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RAE-B ANTENNA ASPECT SYSTEM

FINAL REPORT

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Details of illustrations in this document may be better studied on microfiche

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CONTENTS

SECTION 1

INTRODUCTION

This report summarizes the development of a facsimile camera to serve as the antenna aspect system for the second generation Radio Astronomy Explorer Satellite designated RAE-B. The camera system consists of two cameras and a data encoder as shown in Figure 1. The program deliverables were two flight cameras, a flight encoder and one spare flight encoder.

The RAE-B satellite was originally intended for an earth orbit mission and the facsimile subsystem characteristics were specified with this in mind. Subsequently the flight mission was changed to orbit the moon; however the change occurred too late to significantly influence the facsimile system design. Therefore, this report considers only compliance of the system to earth orbit requirements.

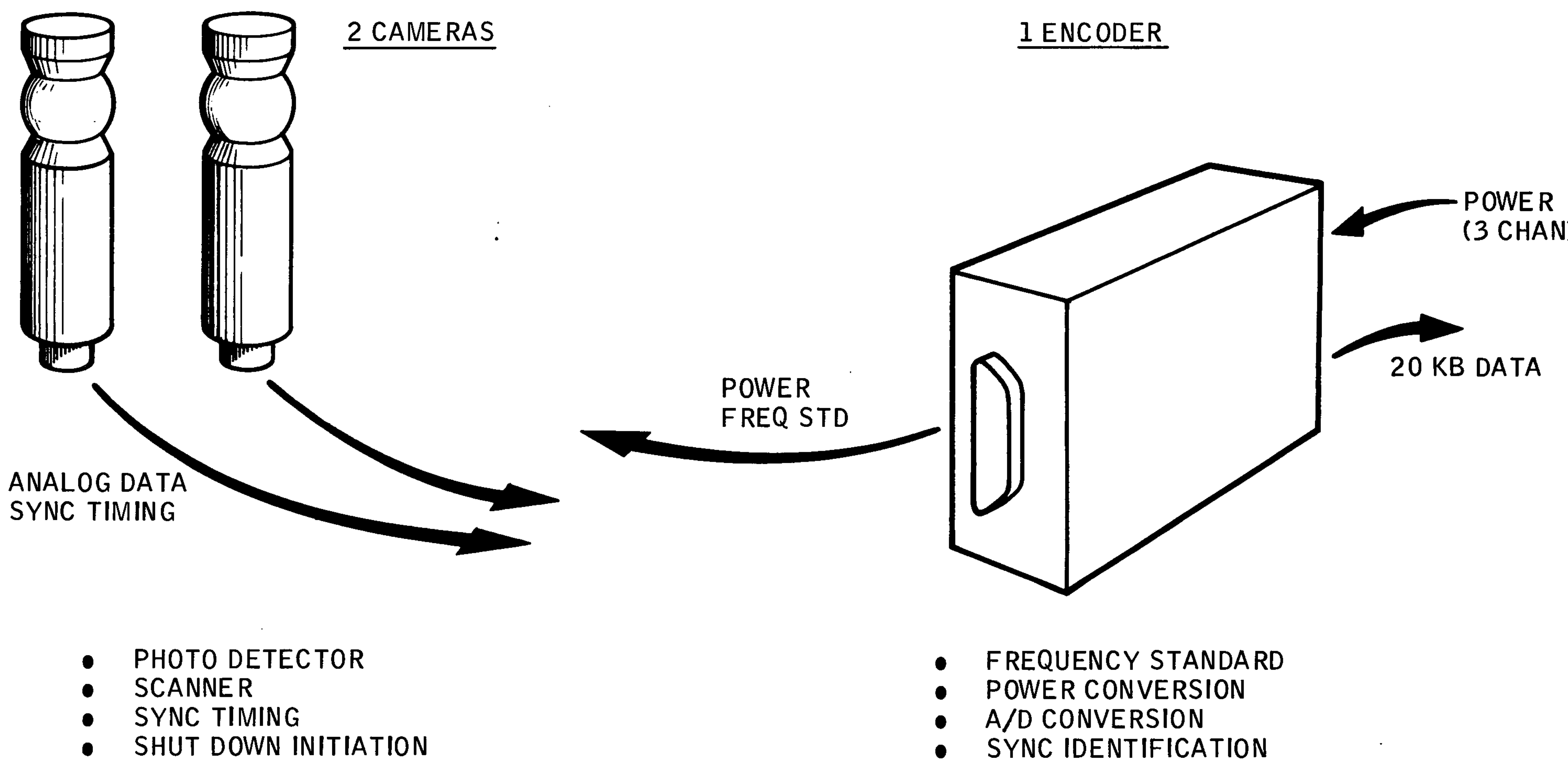


FIGURE 1. RAE-B ANTENNA ASPECT SYSTEM

SECTION 2

DESIGN REQUIREMENTS AND APPROACH

2.1 Design Requirements

The cameras on the RAE-B Satellite are required to observe targets attached to the extremities of four 750 foot antenna booms and record their angular positions with respect to the spacecraft structure. The angular deviation of the booms from their normal positions is to be determined to within $\pm 0.35°$ with a design goal of $\pm 0.25°$.

The cameras are to be mounted on the satellite solar panel structures, projecting outward from opposite sides of the satellite so that all booms are framed in the $70° \times 360°$ field of view of each camera. Camera operation is to be controlled by ground command, and complete sets of image data are to be obtained within the 40 minute view period of a receiver station. Camera data are to be digitally encoded into 4-bit words to match the 20 kilobit/second (kbps) capacity of the satellite transmitter, and are synchronized to allow display on a 512 line TV screen at the control center.

The detailed system requirements are summarized in Table I.

TABLE I

SUMMARY OF DESIGN REQUIREMENTS

BASIC REQUIREMENT:	. Establish position of 4 antenna arms
PERFORMANCE REQUIREMENTS:	. 70° x 360° field of view in 512 lines
	. Present image in 15 gray levels (4 bit endoding)
	. Detect targets at end of each 750 foot boom
	. Establish target positions to within ±0.35°
	. Include sun in field of view
INTERFACE REQUIREMENTS:	. Weight less than 8.7 pounds
	. Power required less than 6.5 watts
	. Maximum data bandwidth of 20 kilobits per second
	. Frame and line syncs
	. Exact line length
	. Selective initiation of either camera
	. Preset frame termination
OPERATING ENVIRONMENTS:	. Temperature Range -15°C to +50°C
	. Vibration -15g
	. Atmosphere - space vacuum
	. Radiation - near earth
	. Life cycle - 1 year

2.2 Design Approach

The facsimile camera system selected for attaining the above requirements scans with a very narrow field of view photosensor to obtain a video analog of the scene. The scene may be reproduced by scanning a video modulated light beam over a rotating drum of photographic film, by an image reproducer, by an equivalent cathode ray tube or by a computer generated display. The technique allows data obtained from an exceptionally large angular field of view to be presented in a single continuous raster.

The camera data rate is extremely flexible, which allows the output to be matched directly to a broad range of transmission data bandwidths without requiring pre-transmission storage for time buffering. Continuity of data acquisition enables immediate presentation of an entire scene with maximum data transmission efficiency. Because of the inherent accuracy of the synchronously integrated scan-and-reproduction systems, photogrammetric quality of the data is maintained.

The radiometric dynamic range of the photosensor is extremely broad and linear, permitting direct transmission of data as received from the scene without optical gain regulation, so that informational quality of the data is maintained. Further, the sensor is not damaged by directly viewing the sun, an important consideration for the RAE-B satellite application.

Low power requirements and solid-state ruggedness of the camera make it characteristically a compact, shock and vibration resistant package. Survival of high impact shock and vacuum operation has been demonstrated by repeated impact testing followed by hundreds of hours of hard-vacuum operation of facsimile camera systems and components.

SECTION 3

SYSTEM DESCRIPTION

The RAE-B Camera System consists of two separate cameras and a data encoder. The camera is mounted in the satellite structure to obtain image data on the behavior of four antenna booms. The encoder converts the camera video signals into a synchronized digital format suitable for delivery to the satellite transmitter and subsequent direct injection into the control center data processing equipment.

The Camera is a small, fixed parameter unit which obtains the image of a 70° x 360° sector field of view in a single frame with a helical line scan format. The camera scans by rotating the narrow field of view of its detector circumferentially about its center line while slowly progressing the line scan elevation angularly downward in a direction parallel to the camera axis. The camera field of view, resolution, and scan rate are specifically tailored for RAE-B Antenna Aspect System requirements to provide accurate angular location of all four satellite antenna arms in each field of view, while constraining data output to the bandwidth of the satellite communication system and the total capacity of the control center display. It is designed to survive launch and operate in the vacuum environment of space for a minimum of one year.

Figure 2 is a functional block diagram of the Encoder electronics for the Camera Subsystem. This unit provides the following functions:

- Command interface
- Power conversion and control
- Clock generation
- Camera switching
- 4-Bit A-to-D conversion of the camera output
- Line synchronization encoding
- Line identification
- Camera identification
- Output buffering and bi-phase conversion

Input commands energize power switches for the single selected camera and simultaneously activate the signal and sync switches which gate the selected camera outputs to a common electronic assembly. The command also provides camera data identification which is inserted into the output bit stream at the proper time in the format.

3.1 Camera Assembly

An isometric breakaway view of the RAE-B Camera Assembly is shown in Figure 3.

The camera is assembled in a metallic tube interrupted near the upper end by a spherical optical window. The portion above the window contains an optical telescope, a video sensor and a video amplifier. A small tube is used as a conduit and shield for the wires leading from the video circuit. An upper bulkhead, with a small purge/seal hole is attached to the top end of the tube by Electron Beam welding. The scanner drive assembly is contained below the bulkhead with the scan mirror and shroud extending into the optical window.

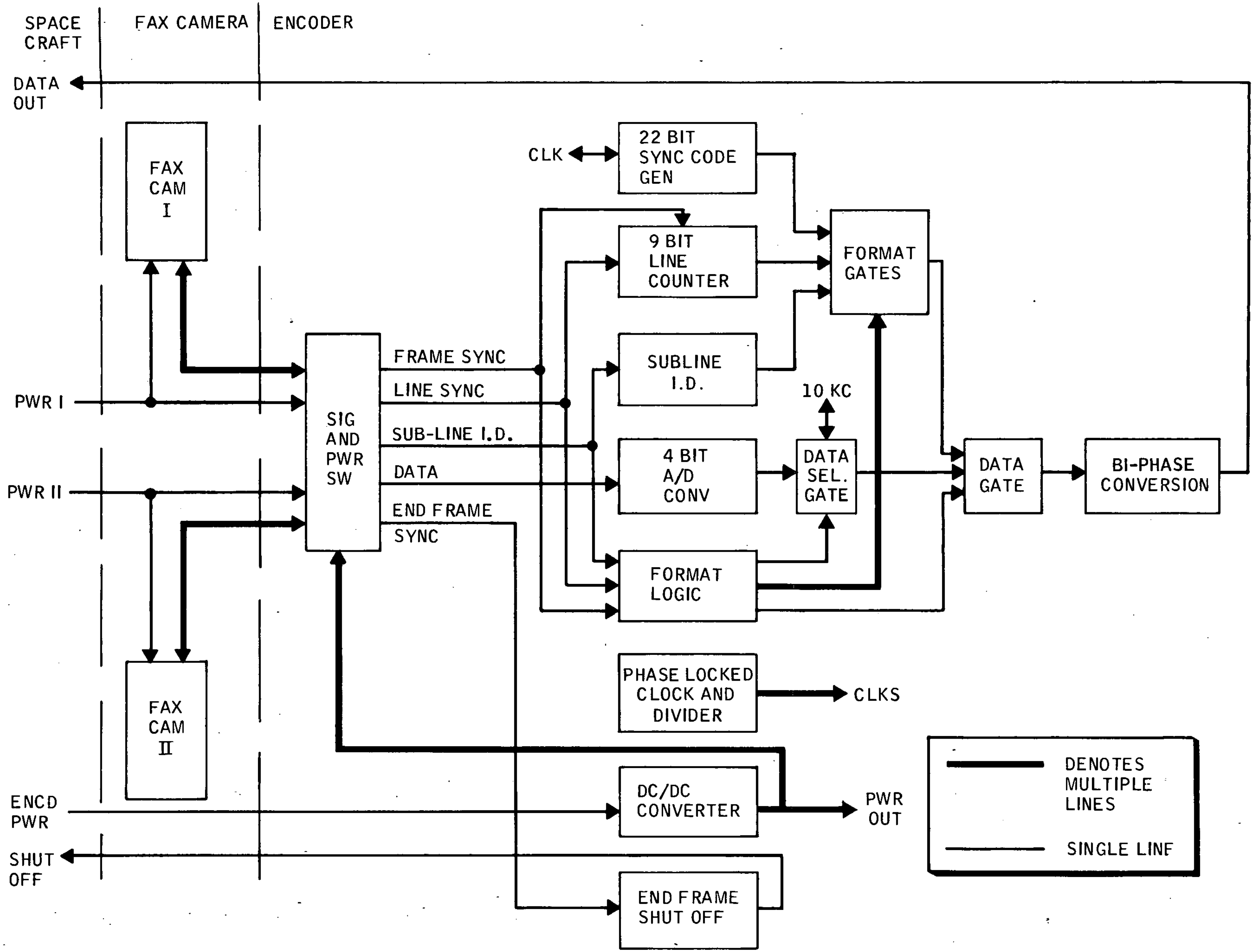


FIGURE 2. ENCODER BLOCK DIAGRAM

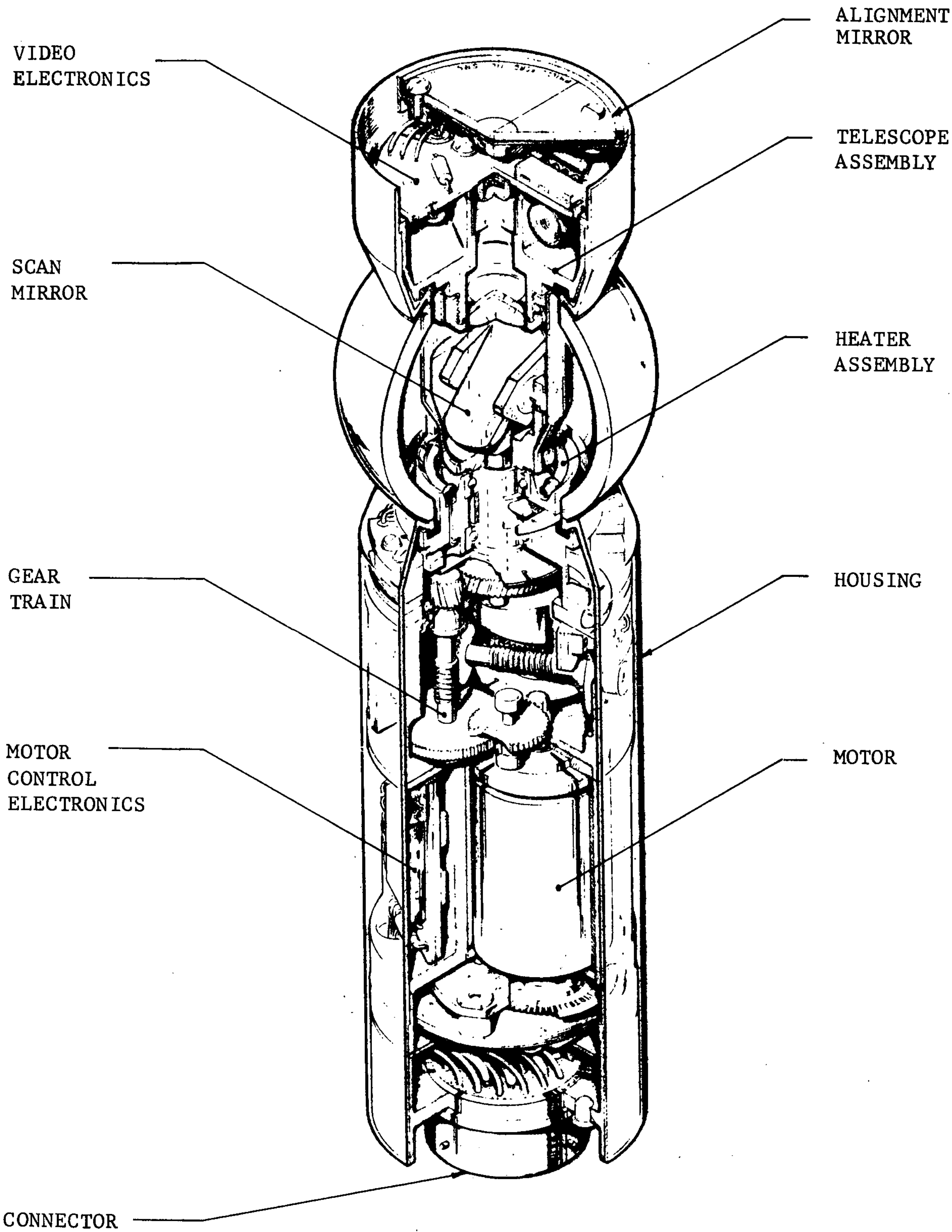


FIGURE 3. CAMERA ASSEMBLY

The scanner drive assembly contains a motor, gearbox, drive/control electronics and all the required sync generation pick-offs and circuitry. A hermetic connector, integral with the lower bulkhead is welded to the bottom of the tube to provide the electrical termination for the camera assembly. A small purge/seal hole is also provided in the lower bulkhead. After assembly, the unit is pressurized with one atmosphere of clean dry nitrogen via this purge hole. An alignment mirror is attached to the top of the camera to provide the capability for camera optical alignment with the spacecraft.

The camera operates by scanning the video sensor's field of view through 360° in azimuth and the required ±35° in elevation. This is accomplished by spinning the mirror in azimuth while simultaneously changing its elevation angle with a gear driven cam and linkage. (See Figure 5). A gearbox driven by the motor provides the required spin rate and cam speed for the mirror. Sync signals corresponding to the beginning and the middle of a scan line and also with the beginning of a frame are generated by optical pickoffs associated with the motor, gear box, scan mirror, and cam. The video sensor produces an output voltage in response to targets in the field of view as they are scanned by the mirror. This voltage is amplified and supplied as a camera output to the encoder for analog to digital processing and insertion into the data format.

3.1.1 Scanner Assembly

The scanning accuracy requirement is such that the angular deviation of the target booms can be detected to within $\pm 0.35°$. This accuracy is achieved by utilizing a high precision gearbox and controlling the drive motor speed very accurately. In addition, constant errors (i.e., errors that repeat) of position in image space can be corrected by means of data derived during calibration.

Synchronization of the camera scan to the encoder digital data is achieved by phase-locking the camera motor to the data clock in the encoder. Sync signals are generated at the beginning of each scan line and at the 180° point in each scan line to insure proper formatting of the output data. An end of frame sync signal is generated to indicate the last data line and to reset the line counter for the next frame.

A block diagram of the scanner is shown in Figure 4, while the important mechanical drive components are shown in Figure 5, and Figure 6 shows details of the scanner head.

Special controls and microscopic inspections were implemented to insure that all scanner parts operated properly. Each scanner assembly was then tested for smoothness and repeatability to insure that the scan accuracy was within the required limits. An example is the gearbox smoothness test set-up shown in Figure 7. A synchronous motor was used to drive the gear box at a constant speed. The rate table was adjusted to run in the opposite direction at the exact speed which caused the target arm attached to the output shaft to remain stationary. The Optron then detected the minute random and repeatable errors of the gear box. A sample plot of this data is shown in Figure 8. Gear box errors were found to be within the required limits.

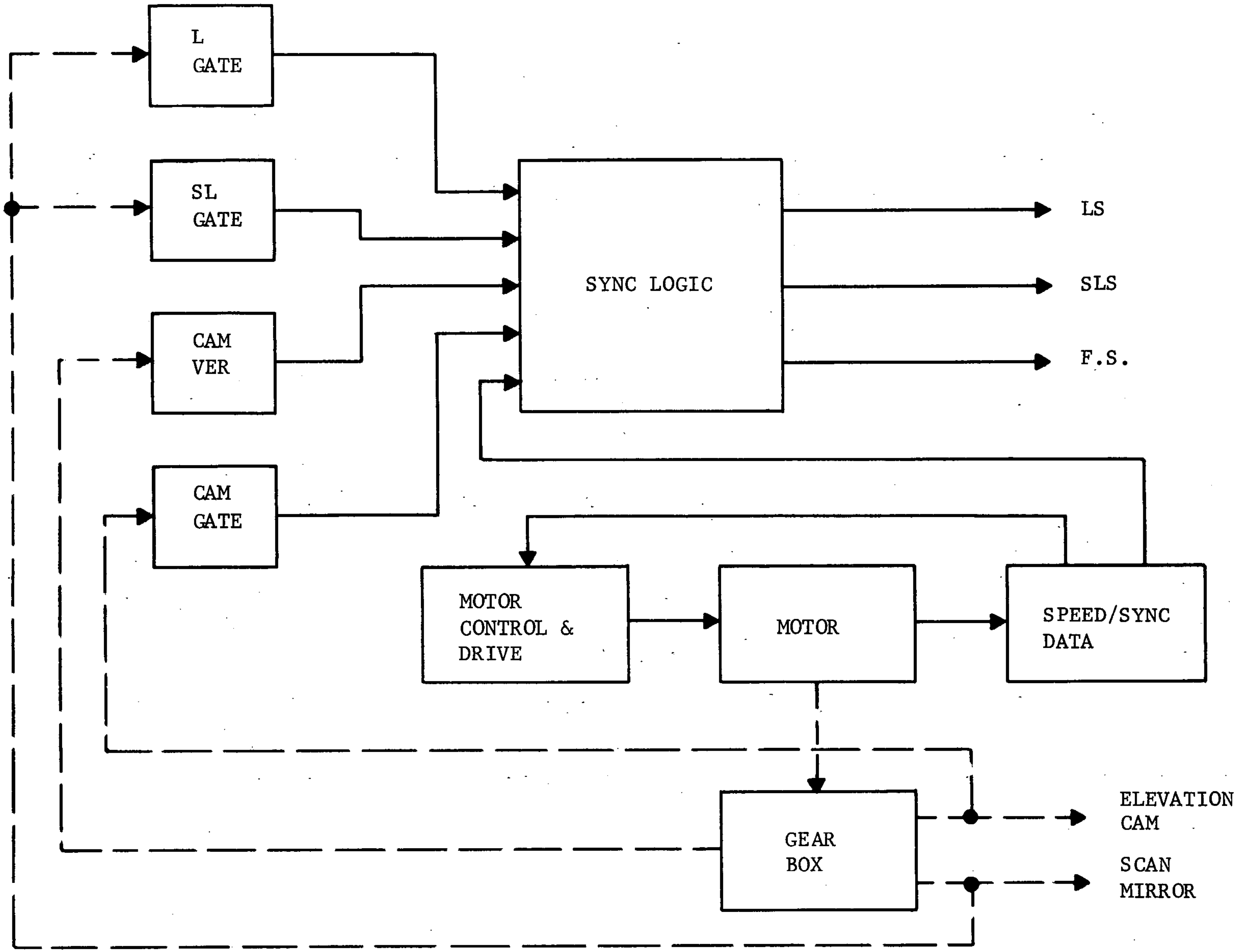


FIGURE 4. SCANNER BLOCK DIAGRAM

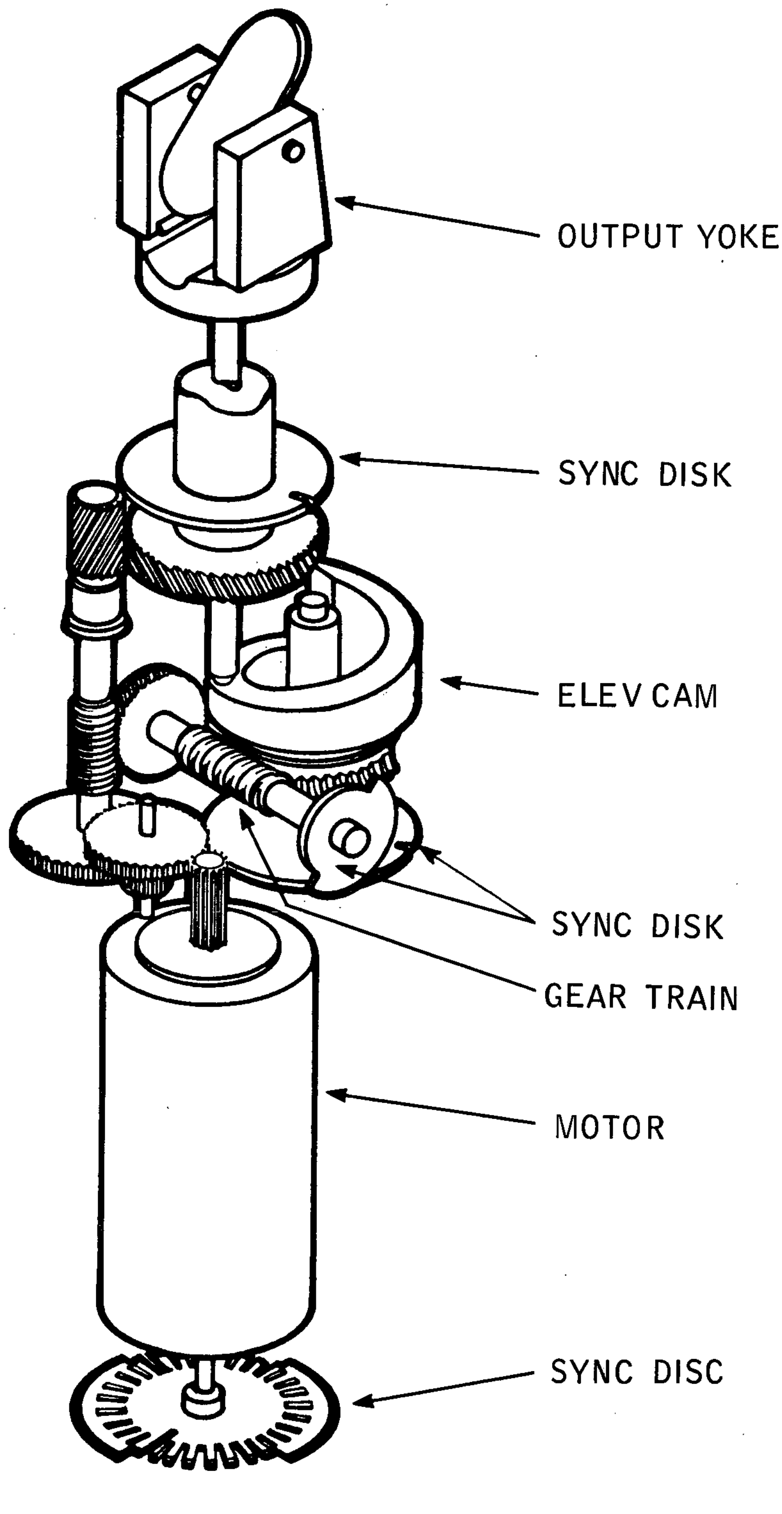


FIGURE 5. SCANNER DRIVE ASSEMBLY

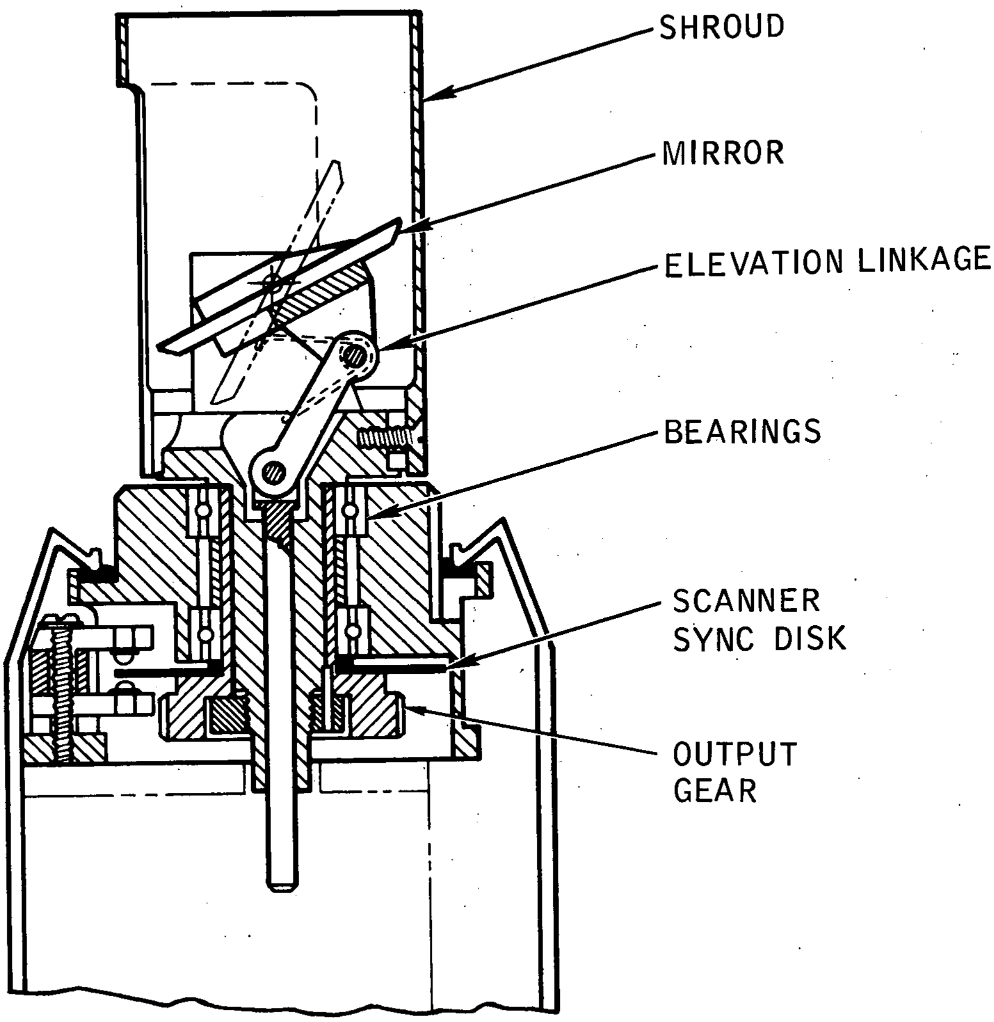


FIGURE 6. SCANNER HEAD ASSEMBLY

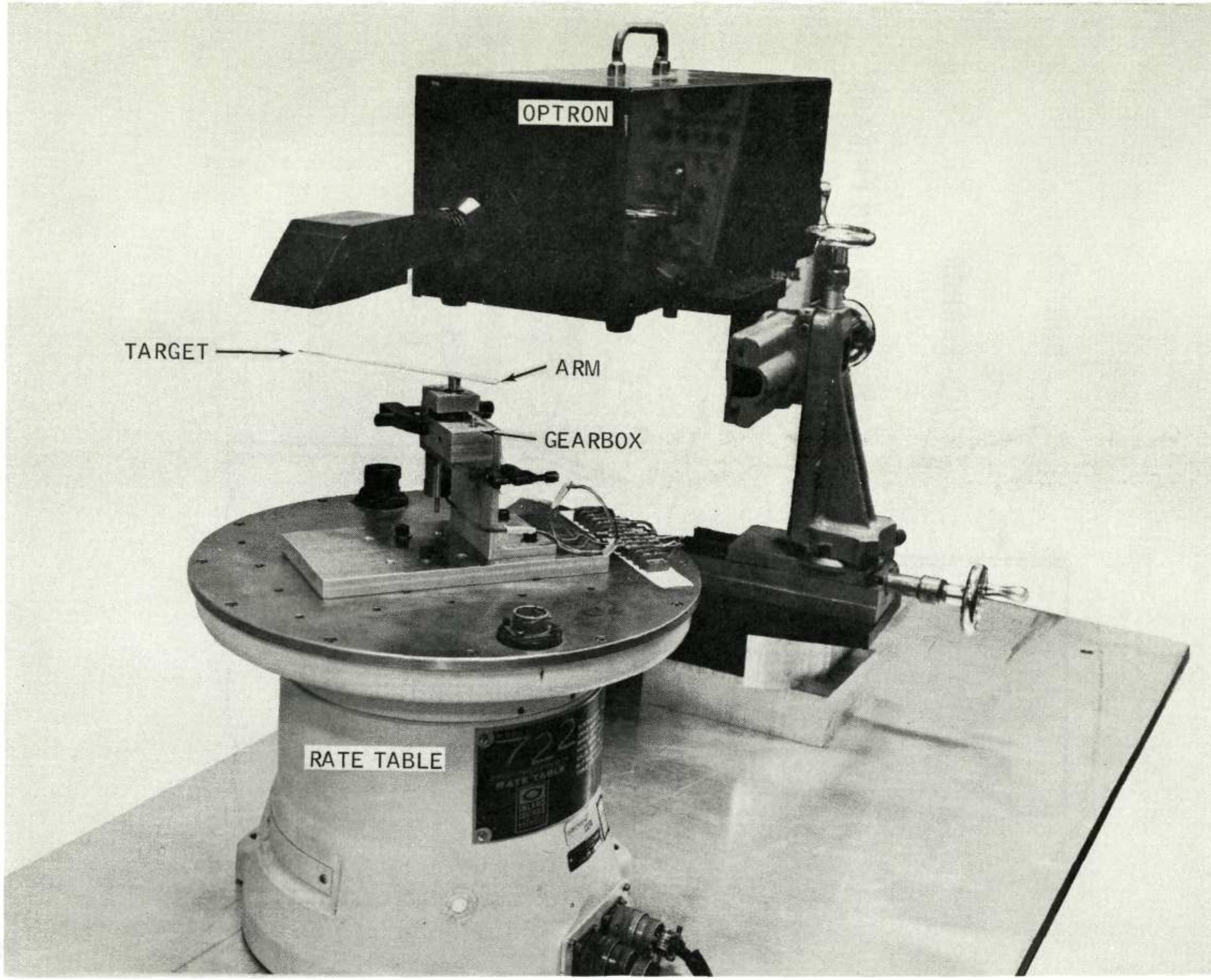


FIGURE 7. GEARBOX SMOOTHNESS TEST SET-UP

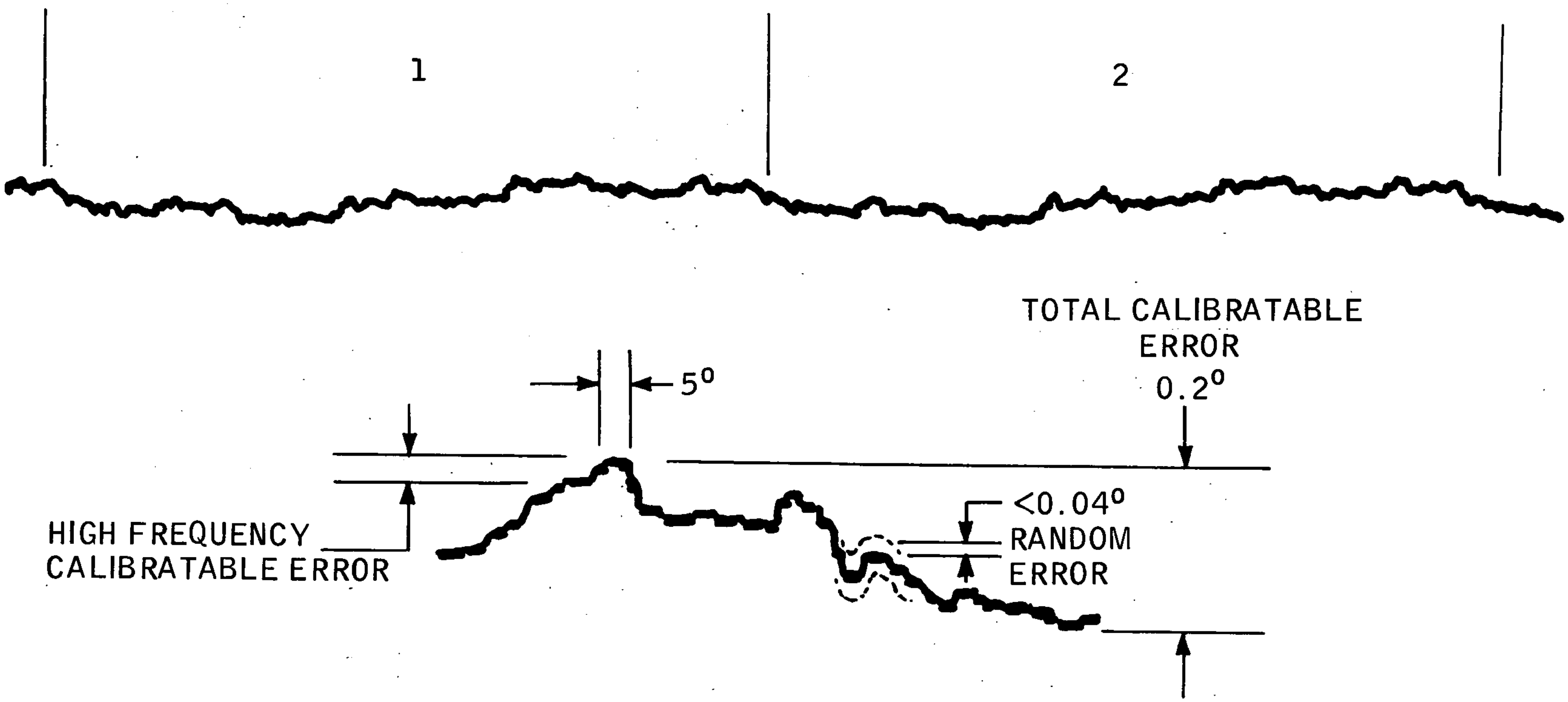


FIGURE 8. GEARBOX SMOOTHNESS DATA

The gear box is driven by a small brushless DC motor. The motor is equipped with a control which synchronously phase locks the rotation of its rotor with a 10 kHz clock signal supplied by the encoder. A motor vernier signal is generated once each motor revolution by the motor encoder wheel. Line and subline sync gates and a frame gate signal are generated in the gearbox. All of these signals are applied to a logic circuit to produce line, subline and end-of-frame sync signals.

The motor speed selected was 9375 rpm. The total motor control and drive power consumption is less than 1.5 watts.

Tests of the motor control system indicated instantaneous motor shaft error of less than 0.5°. This system is shown in block diagram form in Figure 9.

The pick-offs used to generate the sync gate, and motor control signals are small light emitting diode (LED) sensor pairs between which chopper disks are rotated. Hybrid integrated sensing amplifiers detect the gate signals and amplify them up to standard digital logic signal levels. The synchronization system arrangement is shown in Figure 10. All of the necessary LEDS are driven in series with a temperature compensated current source of approximately 35 mA.

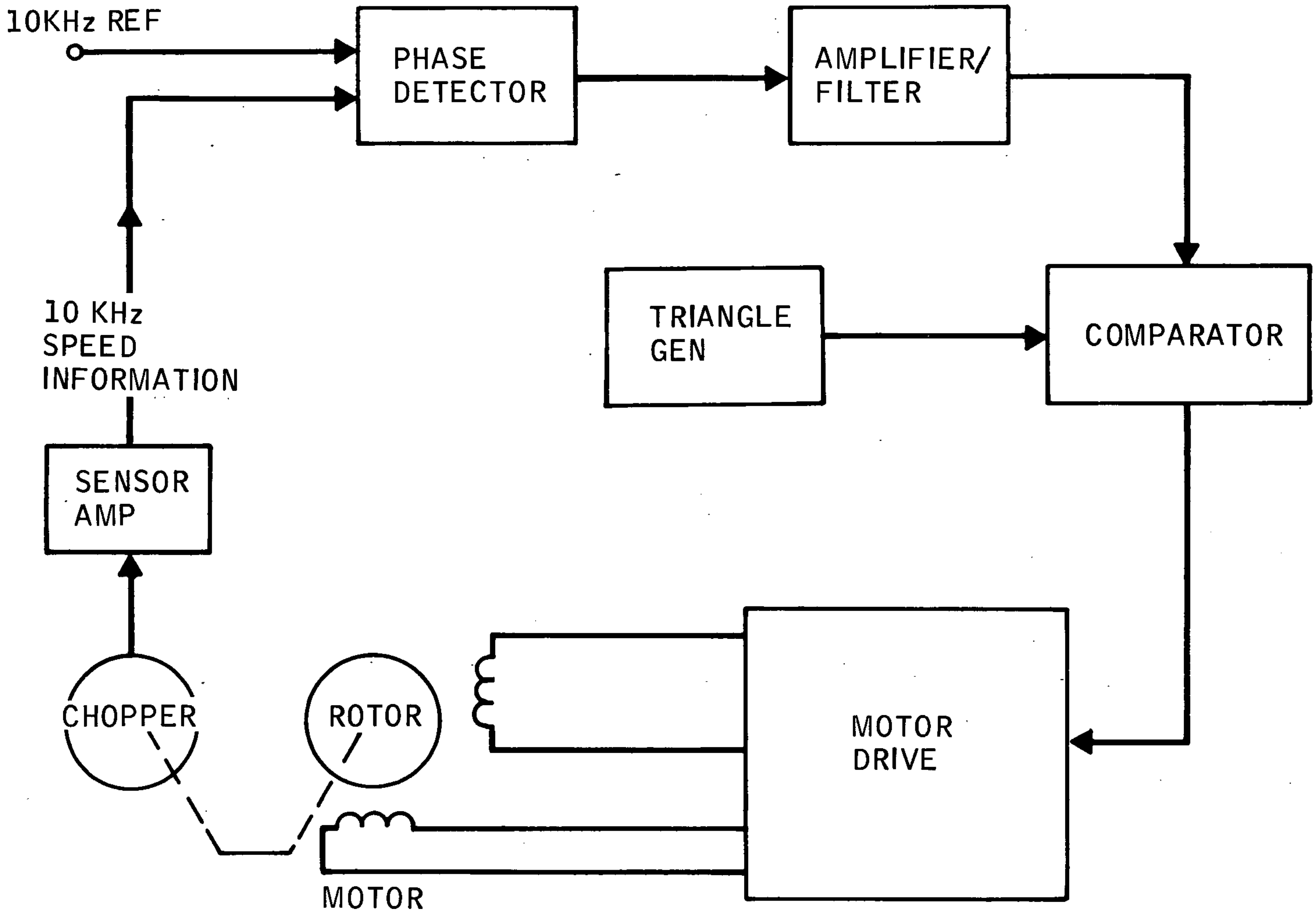


FIGURE 9. MOTOR CONTROL SYSTEM BLOCK DIAGRAM

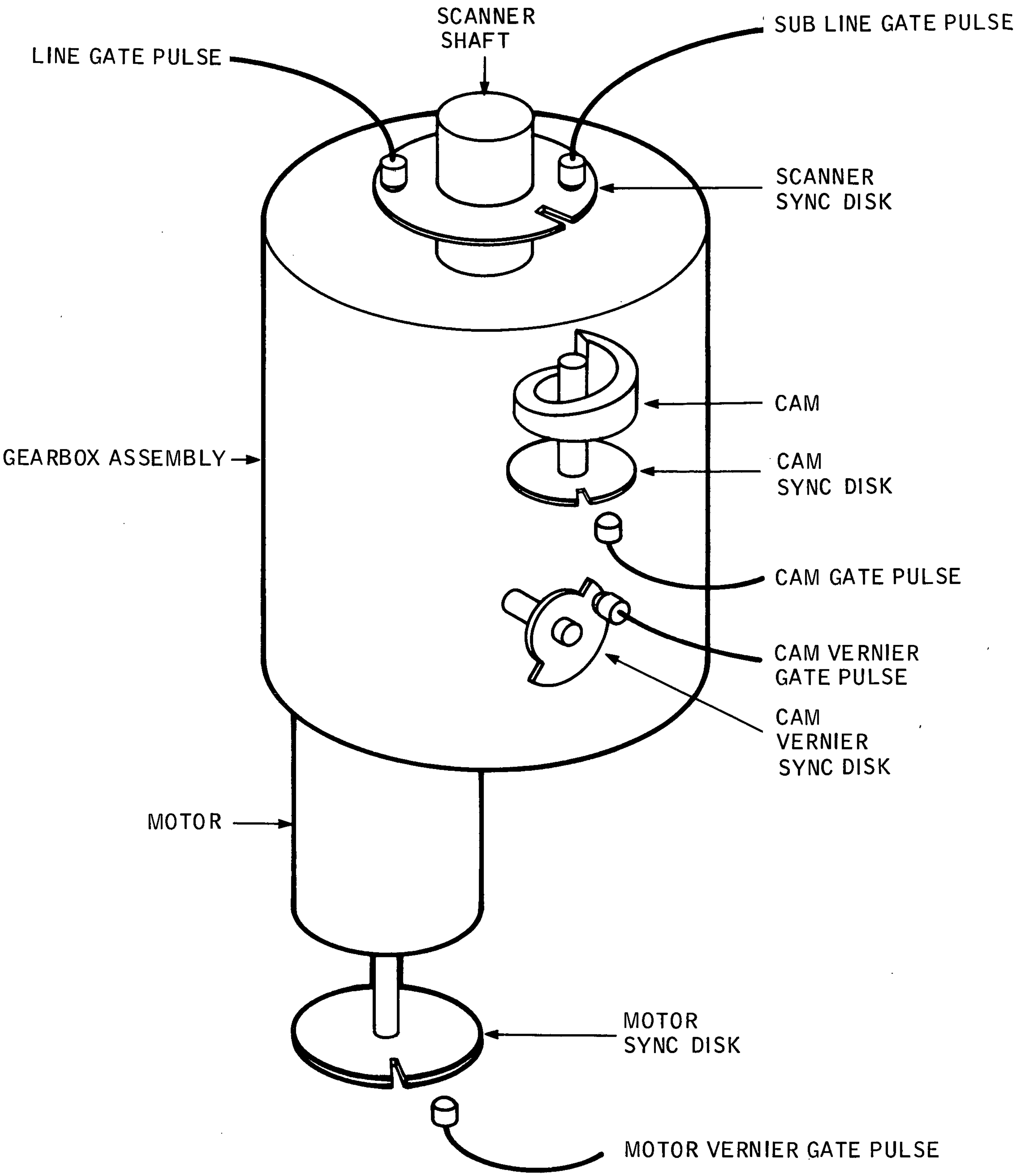


FIGURE 10. SYNCHRONIZATION SYSTEM

3.1.2 Optics

The elements of the optical system are shown in Figure 11. An optical ray trace is given in Figure 12.

The spherical viewing window is the initial element in the optical train. It is fabricated from fused silica which is a high purity synthetic quartz. This material was chosen for its excellent resistance to discoloration or optical darkening due to prolonged solar radiation exposure and for its lack of flouresence upon exposure to ambient radiation.

Special tooling was developed to grind and polish the inner and outer surfaces of the spherical window. Upon delivery these windows were optically inspected in a setup similar to that shown in Figure 13 to determine the limits of astigmatic distortion. Initial tests were conducted in one plane with a cylindrical window. The final tests were conducted with a full spherical window viewed through both walls. In the latter tests the sphere was rotated about its horizontal axis to check for distortion about the entire viewing angle.

A scan mirror located at the center of the window directs the incoming rays into the objective lens. This lens is designed to correct chromatic aberration across the 0.4 to 1.1 micron response band of the silicon detector. The relative drop off in detector response at both ends of the band allowed for the use of a simple two element design.

A single baffle is used to absorb internal reflections due to off axis rays. The system provides essentially complete isolation from the sun 3.5° off axis.

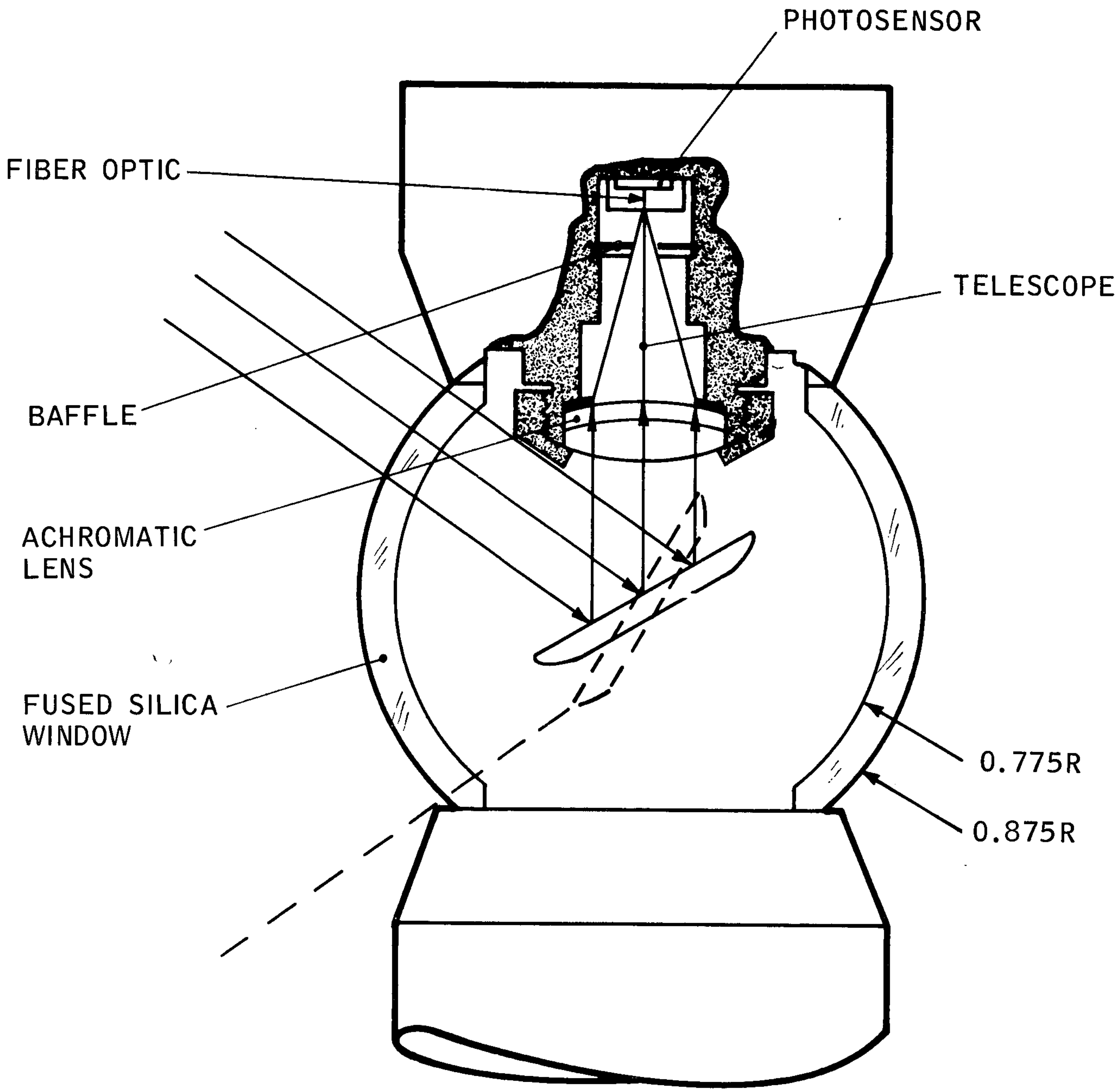


FIGURE 11. OPTICAL SYSTEM

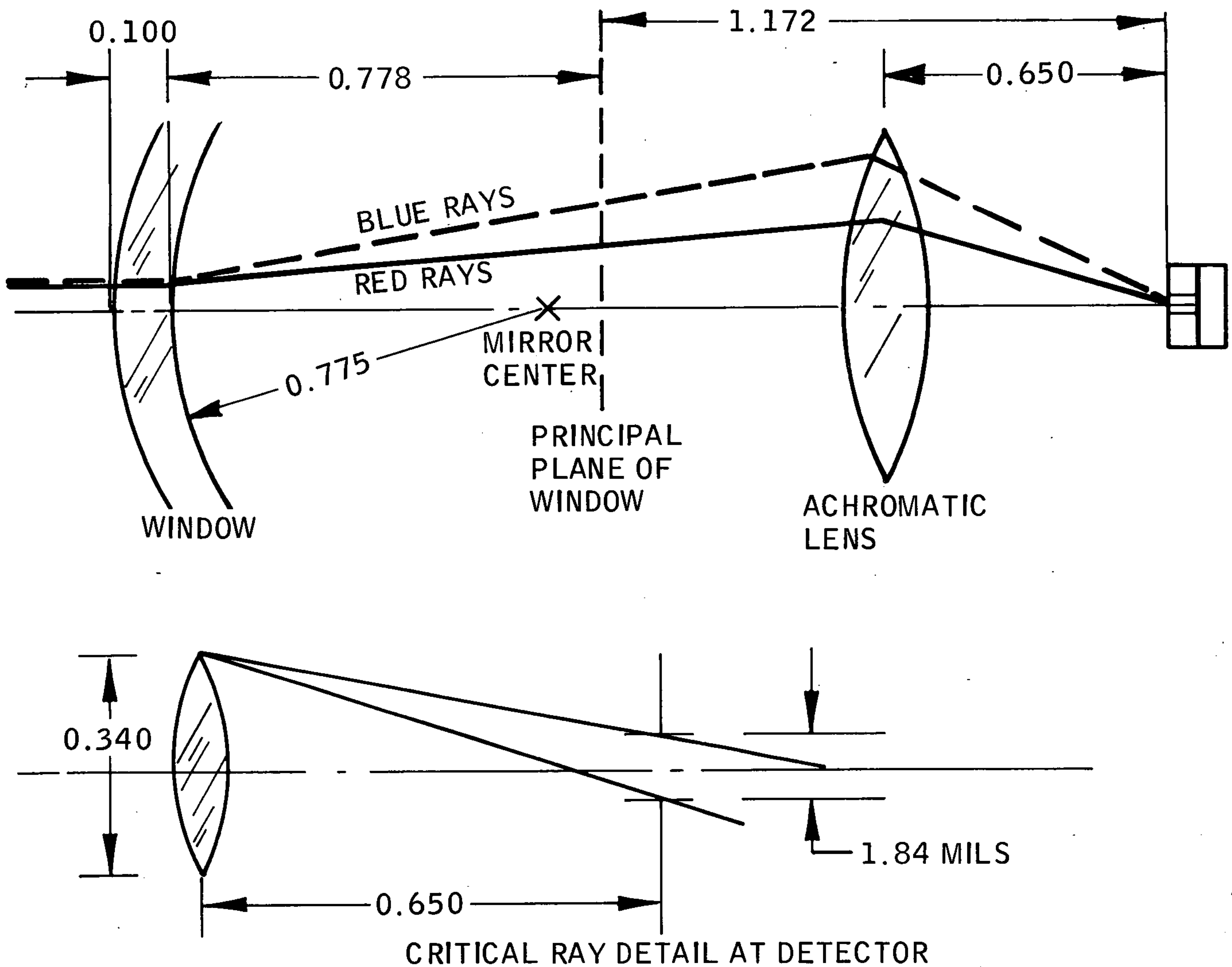


FIGURE 12. OPTICAL RAY TRACE

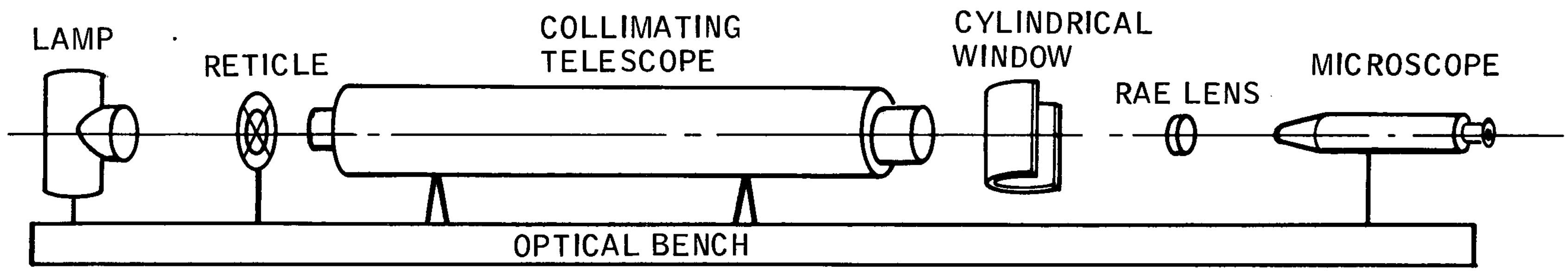


FIGURE 13. WINDOW ASTIGMATISM TEST SET-UP

The system is apertured by a 2.16 mil diameter fiber which conducts the light rays to the video sensor chip. This fiber also serves to thermally isolate the detector from damage during non-scan view of the sun.

Special measures were taken to prevent fogging of the optics. A low vapor pressure lubricant was used; absorbtive materials were avoided; and extensive vacuum baking was employed. A low outgassing heater located near the lower edge of the window with its reflector directing heat towards the window was used to prevent migration and condensation on the optics.

Figures 14 and 15 describe the scene photometry and geometry in terms of object brightness and angular size. Figure 16 shows the typical video signal response seen as a target ball is scanned.

3.1.3 Video Subsystem

The video subsystem consists of three major parts: The senser/preamplifier hybrid, the video amplifier hybrid and the DC restorer hybrid. A block diagram showing the interelationships of these elements is given in Figure 17.

a. Sensor

A silicon photodiode was selected as the photosensor in the RAE-B cameras for reasons of low noise, large dynamic range, good responsivity, complete insensitivity to high level light input and availability.

OBJECT	REFLECTANCE (PERCENT)	BRIGHTNESS (FOOT-LAMBERTS)
TERRAIN	18	
NOON		2350
SUNSET		7.6
OCEAN	5	
NOON		653
SUNSET		2.1
CLOUDS	70	
NOON		9140
SUNSET		29.4
FULL MOON	10	1305

WHERE SUN $\Rightarrow$ 13,050 FOOT-CANDLES AT NOON

42 FOOT-CANDLES AT SUNSET

FIGURE 14. SCENE PHOTOMETRY

OBJECT	ANGULAR SIZE	
	MILLIRADIANS	DEGREES
12 IN. TARGET BALL	1.33	0.076
SUN, MOON	9.04	0.517
EARTH	1002	57.4
RAE FAX IMAGE ELEMENT	2.9	0.1667

FIGURE 15. SCENE GEOMETRY

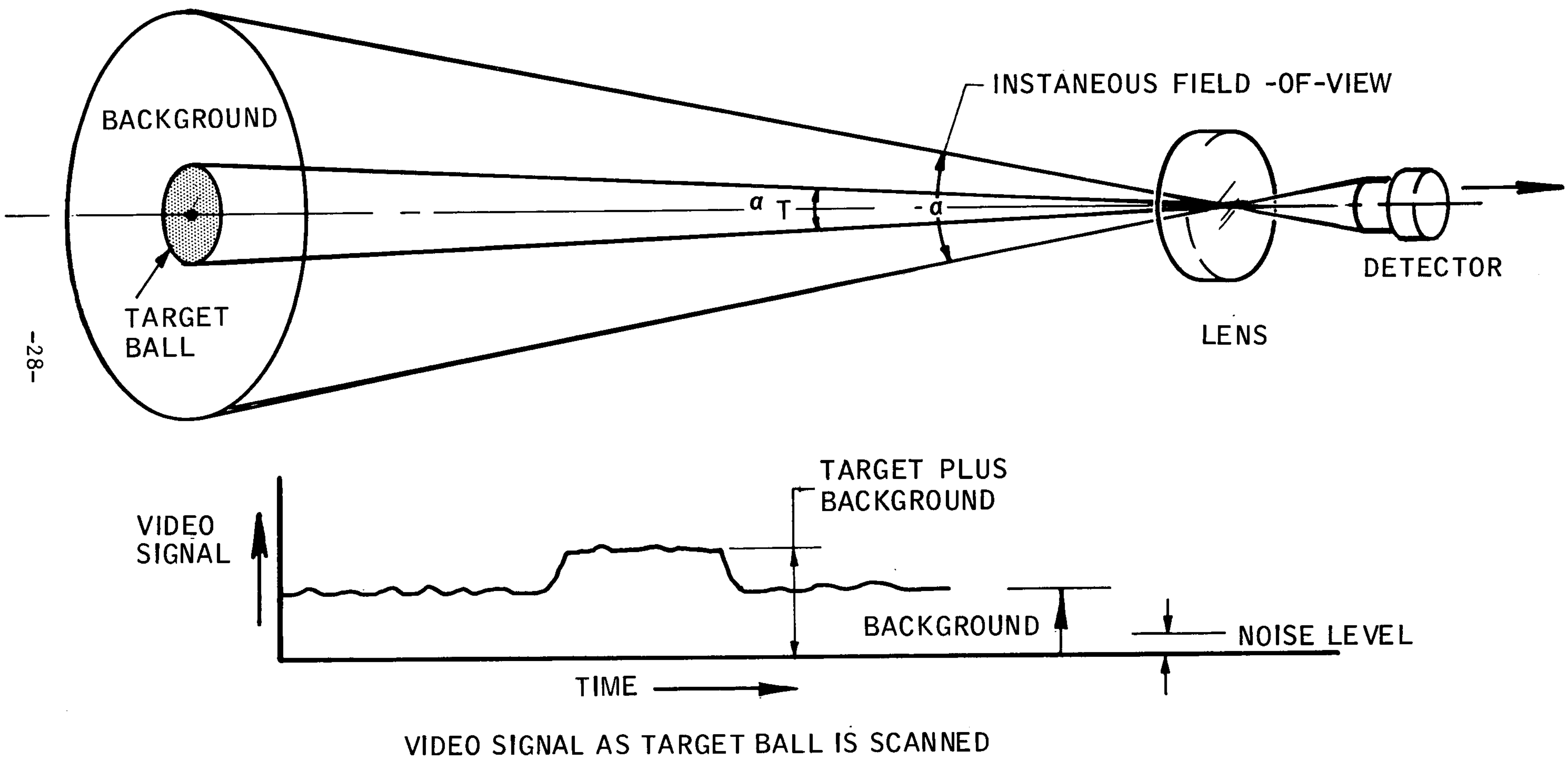


FIGURE 16. VIDEO SIGNAL AS TARGET BALL IS SCANNED

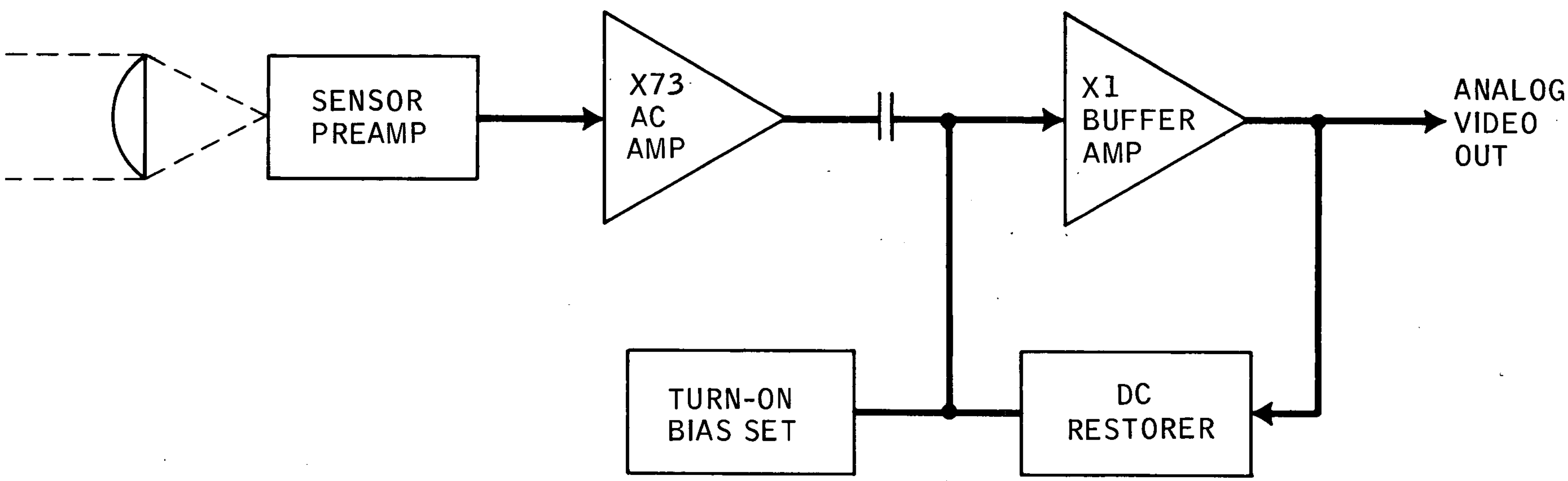


FIGURE 17. VIDEO ELECTRONICS BLOCK DIAGRAM

The sensor/preamplifier is a hybrid circuit assembled on a TO-52 header. It contains an HP-5082-4205 PIN photo diode sensor and two 2N4416 FET's. The sensor chip is in the center of the assembly and to it is bonded a fiber optic. This fiber protrudes through the top of the can which is welded to the header. Following assembly the fiber is soldered in place, and then broken off, and polished flat. The result is a hermitically sealed photosenser with an aperture corresponding to the fiber optic diameter. The photosensor specifications are summarized below:

- Effective aperture (fiber) diam = 2.16 mils ± 10 percent
- Maximum light entrance angle = 14.7 degrees from normal (f/1.85)
- Spectral response - 0.45 to 1.0 micron (10 percent points)
- Quantum efficiency = 74 percent at 0.8 micron (peak)
- Maximum incident radiant power (all wavelengths) = 472 watt/cm^2
- Maximum photocurrent 1 mA
- Full scale photocurrent = 2.05 nA (1400 fL)

b. <u>Video Electronics</u>

The camera optics focus the image from each resolution element in image space onto the photosensor. This causes photo-current to flow through a resistor. The voltage across this resistor is amplified, AC coupled to a buffer and then fed to the encoder. The buffered output is also applied to a DC restoring circuit. This circuit compares the output voltage with zero volts (video return) and does not allow the output to become negative. The net effect is to reset the most negative part of the video signal of each scan line to zero volts. In its spacecraft application the predominant background of black space throughout the camera field of view provides a continuous source of reference for zero level. When making pictures on earth, a black vertical target band with a width of at least 10 degrees view angle is placed in the camera's field of view so that the analog video is always properly referenced to zero.

The full scale output range is 0 to +5 volts. The video frequency response extends to 2.5 kHz. The low frequency response is determined by the rate of discharge of the coupling capacitor. This rate is constant and is due to the bias current required by the buffer amplifier. In the RAE-B units this was specified at 100 mV/sec maximum and units were typically less than 50 mV/sec. The effect of this drift is negligible with respect to the target ball signals which are nominally 200 μSec in duration.

c. Assembly and Checkout

The video circuitry is assembled onto a circular board. This assembly is then mounted into a telescope housing and tested for proper operation. Adjustments are made for proper focus and centering of the sensor and for proper electrical operation. The typical input noise voltage for the video system is less than 5 mV rms over the 2.5 kHz bandwidth. The input noise, sensitivity and bandwidth are all controlled by the input resistor. The value of this resistor is determined by the bandwidth and the input capacitance of the photo sensor and is 27 megohms for the RAE cameras.

Response tests were made on the photosensor assemblies. The tests were made in sunlight using a large area sensor as a reference and indicated that the response of the sensors was approximately 80 to 90% of that expected. Calculations based on this data, the sensitivity and noise of the 27 megohm resistor, and the expected brightness of the target balls indicated an acceptable signal to noise ratio for the video system.

3.1.4 Environmental Provisions

The RAE-B Camera System is designed to operate in a deep space vacuum. In order to protect the mechanisms in this environment the cameras are hermetically sealed with an internal atmosphere of dry nitrogen at one atmosphere pressure.

Highly efficient metal/glass seals are provided to survive the 1 year minimum vacuum exposure without appreciable leakage. Several combinations of materials and processes were tested to determine the optimum method of attaching the optical window to the invar housing. Figure 18 shows three test samples used. Helium leak detection tests were performed before and after prolonged exposure of these units to a temperature of minus 100°F. The bulkheads at the camera extremities are sealed by electron beam welding.

Camera materials, bearings and lubricants were all carefully selected to survive the one year operating environment with minimum outgassing. Great care was taken during assembly to insure that all internal parts were extremely clean and free of volatile contaminants which could eventually migrate to the window or optical system. A heater near the window insures that contaminants if any will deposit elsewhere.

The externally mounted cameras are maintained within their required temperature range by the use of externally applied coatings, and the internal, thermostatically controlled heater (Figure 19). The heating element is an annular radiator located around the base

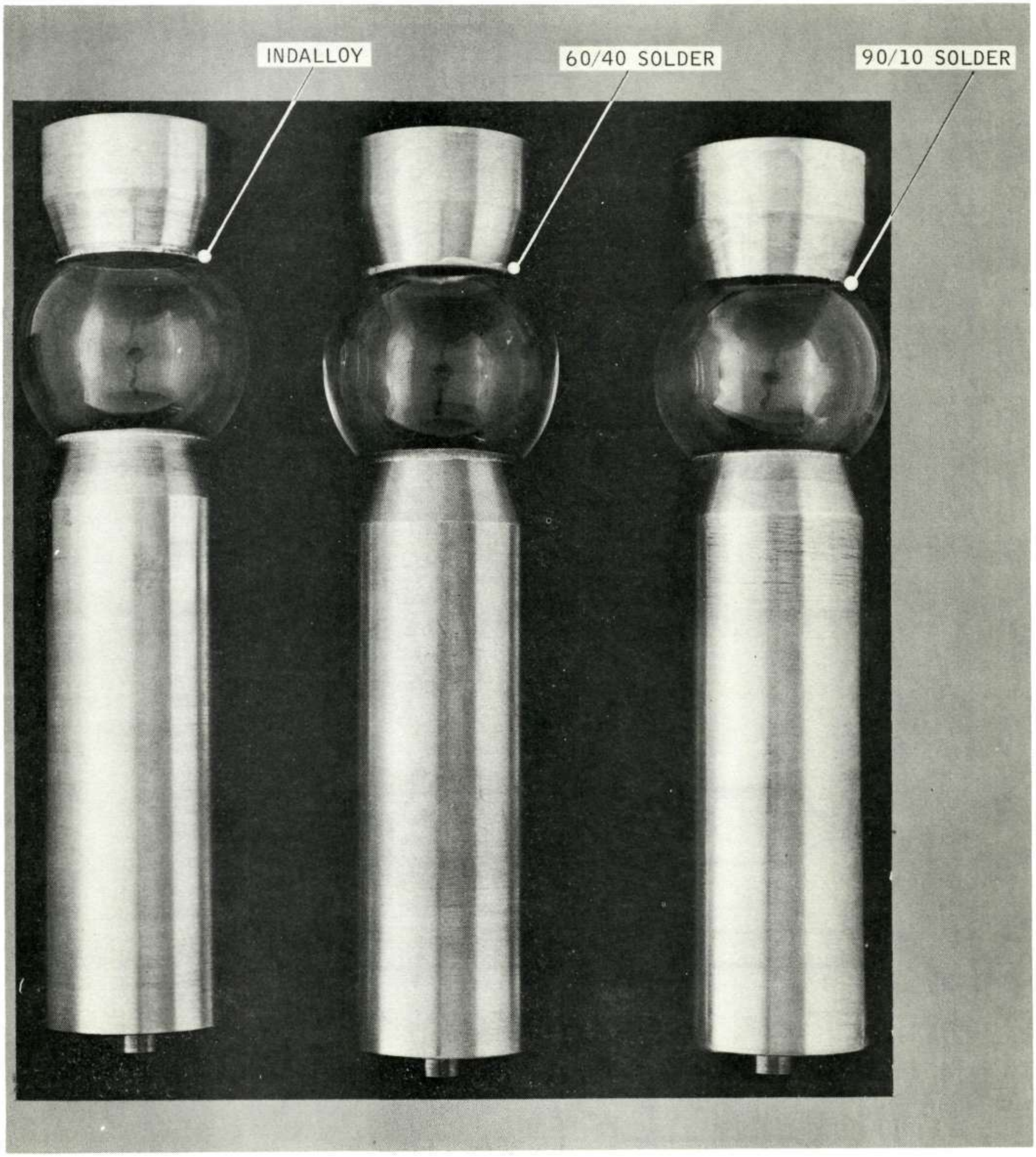


FIGURE 18. HOUSING TEST SPECIMENS

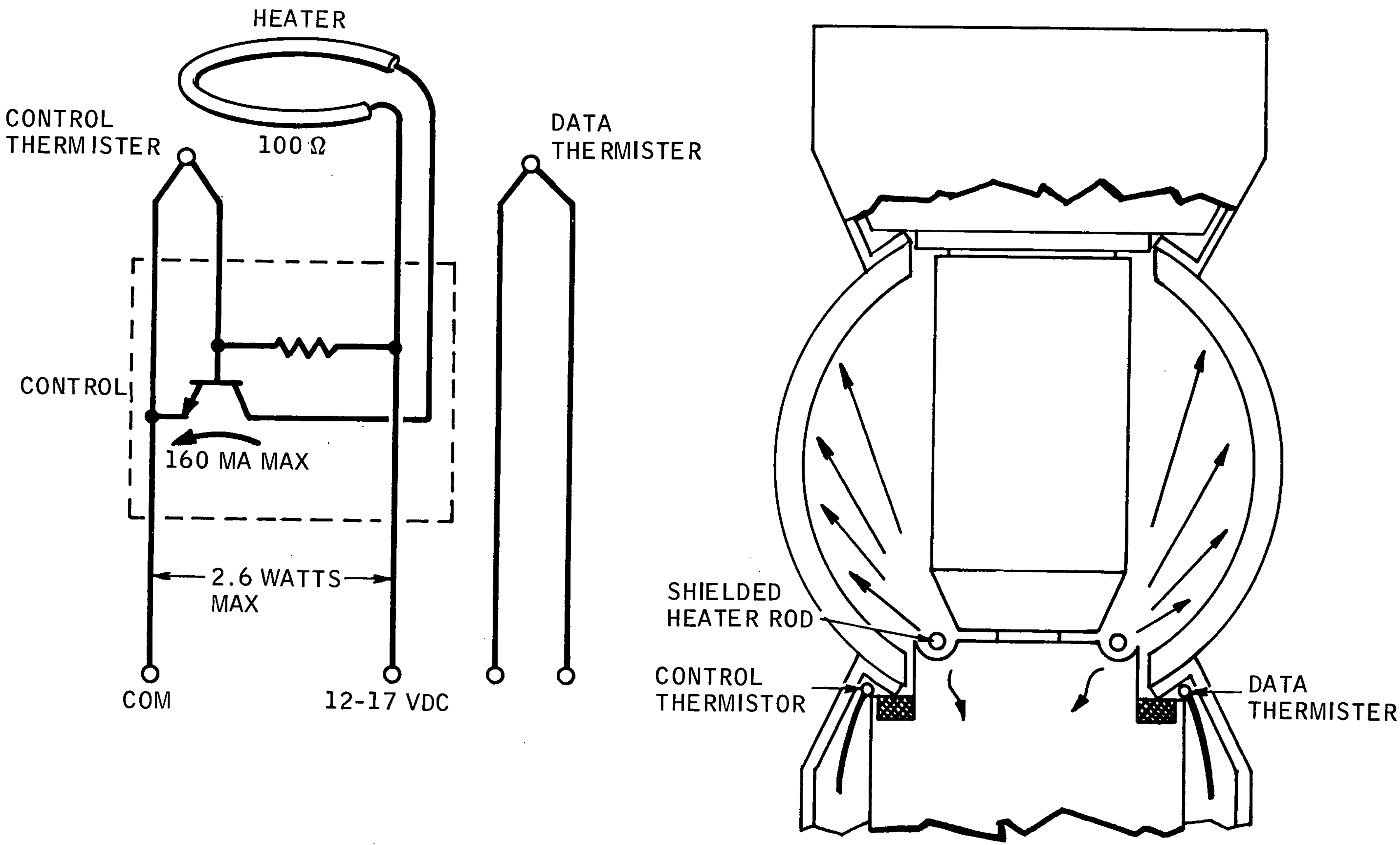


FIGURE 19. THERMAL CONTROL SYSTEM

of the camera window. Temperature monitor and control thermistors are located on the metal housing just below the heating element. The heater resistance is approximately 130 ohms and will dissipate approximately 1.3 watts with +15 VDC applied to the control circuit. This circuit is adjusted so that current will start to flow through the heater between -5°C and -15°C. A typical profile of heater power as as function of temperature is shown in Figure 20. The internal heat paths and sources of heat dissipation during camera operation are summarized in Figure 21.

The solar and Van Allen belt radiation effects were considered in relation to their influence on the operation of the photo-sensor. These potential noise sources could seriously impair system operation. Their influence was minimized by thickening the sensor shielding to the greatest extent practicable. The result is that no more than 30 false signals per frame are expected, except during solar storms. These are readily recognizable and can be eliminated by correlation of sequential frames.

3.2 Encoder Assembly

The Encoder Assembly functions as a power converter and a video data processor for the camera. Its four major subsystems are: the system clock, sync generation and formatting, video data processing, and power conversion and control. All power and signals required for operation of the Camera are routed through the Encoder. These include the +18 volts for camera motor operation, the +12 volts for temperature monitoring, the +12 to 17 volts for heater operation and the signals to command operation of either camera. The system is started by applying power to the Encoder. It is shut down upon receipt of a command from the spacecraft control circuit.

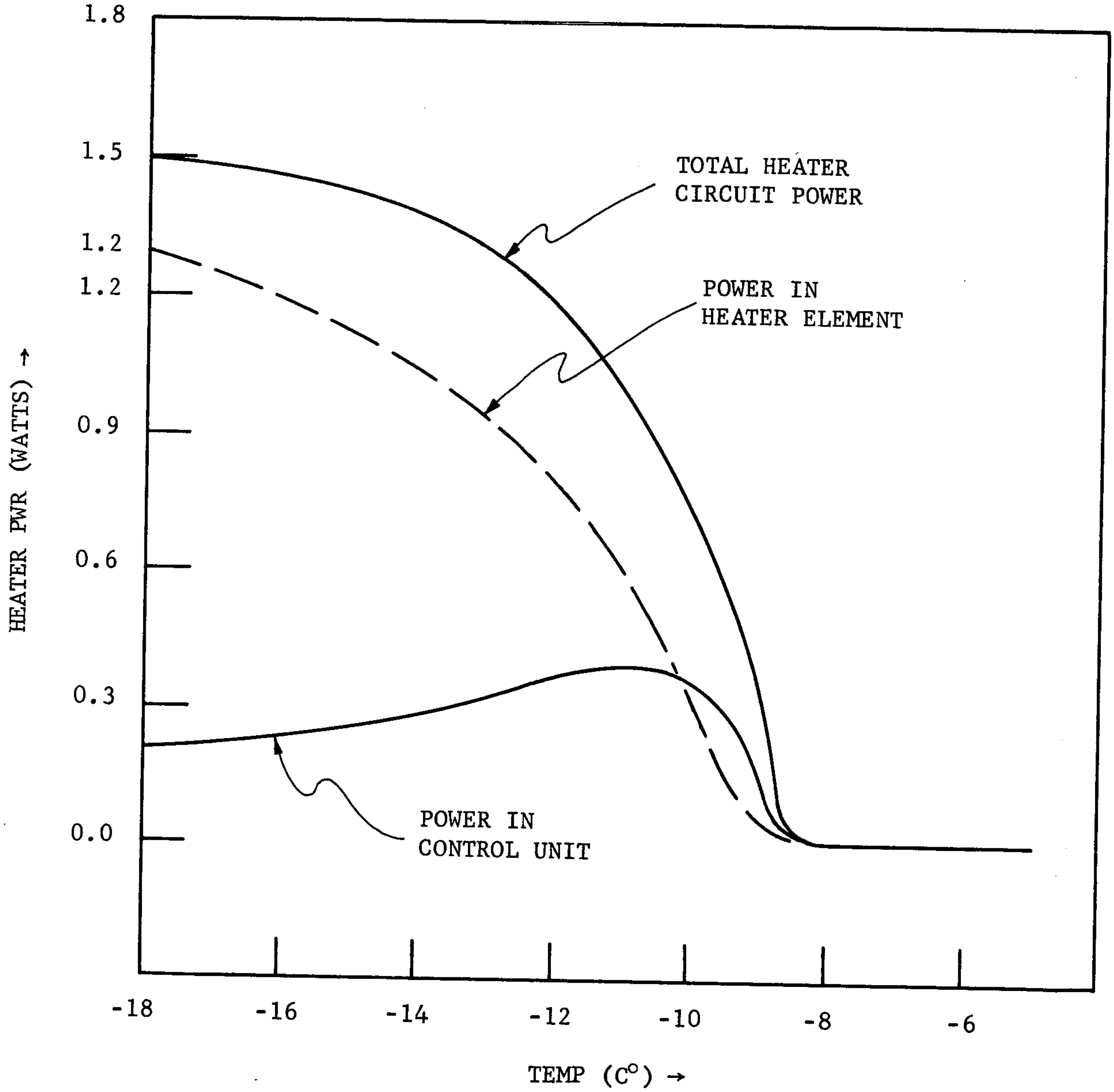


FIGURE 20. TYPICAL HEATER POWER AS A FUNCTION OF TEMPERATURE

HEAT PATHS

VIDEO TELESCOPE

ALUMINUM STRUCTURE SUPPORTING VIDEO ELEC. AND LENS. TOUCHES HOUSING AT UPPER RIM AND AT RFI SEAL AROUND TOP RIM OF WINDOW

TRANSFER TUBE

0.062 DIA, 0.005 THICK STEEL TUBE FILLED WITH 5 NO. 36 INSULATED WIRE. ONLY CONNECTION OTHER THAN WINDOW BETWEEN TOP AND BOTTOM STRUCTURES

WINDOW

1.75 DIA, 0.125 THICK FUSED SILICA SPHERE, SOLDERED TO HOUSINGS

UPPER & LOWER HOUSINGS

1.50 OD, 0.03 THICK INVAR TUBE TRANSITIONS INTO 0.02 THICK CONE NEAR WINDOW

SCANNER STRUCTURE

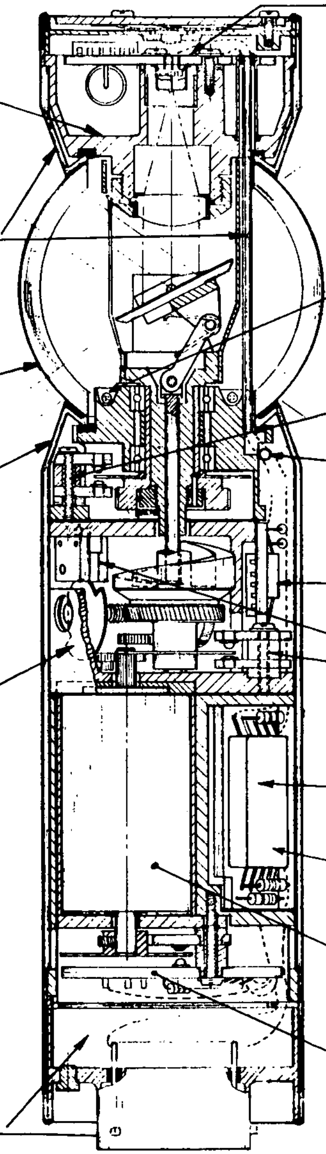
BOLTED TOGETHER ASSEMBLY OF Al. HOUSINGS. "TIGHT" SLIP FIT INTO LOWER HOUSING. GOOD THERMAL JOINTS AT LOWER RIM AND THROUGH RFI SEAL AT BASE OF WINDOW. UPPER END TERMINATES IN REVOLVING CYLINDRICAL SCANNER SHROUD WHICH EXTENDS UP TO BUT DOES NOT TOUCH VIDEO TELESCOPE

BULKHEAD CONNECTOR

INTEGRAL BULKHEAD - HERMETIC CONNECTOR WELDED TO HOUSING (AS IS UPPER BULKHEAD). CONNECTED TO SCANNER WITH 38 NO. 32 WIRES 3.0 INCHES LONG

ATMOSPHERE

1 ATMOSPHERE DRY NITROGEN SEALED IN



HEAT SOURCES, SENSORS

VIDEO ELECTRONICS

0.162 WATTS INTO TELESCOPE STRUCTURE

HEATER

1.3 WATTS RADIATED OUT OF 0.8 DIA RING, 0.07 CROSSECTION DIAMETER MOUNTED IN UPWARD REFLECTOR, WHEN TURNED ON. 0.2 WATTS FROM CONTROL INTO SCANNER STRUCTURE WHEN HEATER IS ON.

LINE SYNC

0.045 WATTS EACH, TWO PLACES INTO SCANNER STRUCTURE

TEMPERATURE SENSORS, MONITOR AND CON

THERMISTERS MOUNTED TO SCANNER STRUCTURE

SYNC ELECTRONICS

0.186 WATTS INTO SCANNER STRUCTURE

FRAME SYNC

0.045 WATTS EACH, TWO PLACES INTO SCANNER STRUCTURE

MOTOR CONTROL

0.202 WATTS INTO SCANNER STRUCTURE (OTHER SIDE)

MOTOR DRIVER

0.76 WATTS INTO SCANNER STRUCTURE AND SHORTED TO HOUSING

MOTOR

0.72 WATTS BURIED INSIDE SCANNER STRUCTURE

MOTOR SYNC

0.644 WATTS INTO SCANNER STRUCTURE

FIGURE 21. RAE-B FACSIMILE CAMERA THERMAL CONFIGURATION

The Encoder is assembled into a 5" x 7" x 1.75 inch frame provided by the customer. Circuitry is mounted on printed circuit boards and power conversion is accomplished by a separate DC/DC converter module.

The design requirements are summarized in Table 2.

3.2.1 Clock

A block diagram of the clock system is shown in Figure 22. A crystal oscillator is used for the basic clock. This oscillator runs at 2.56 MHz. If the crystal oscillator should fail a back-up clock is provided in the form of an astable multivibrator in the countdown circuitry. This multivibrator is synchronized to the crystal oscillator in normal operation but will continue to run in the absence of these sync signals. Clock signals at frequencies of 160, 80, 40, 20, and 10 KHz are generated for use within the encoder. Temperature testing of the encloder verified that the clock is accurate to within a few cycles of 20 KHz over the entire operating temperature range.

The 10 KHz reference signal from the clock is used to phase lock the camera scanner motor and accompanying sync pulses. This signal leads the system data clock (20 KHz) by 6.2 μsec. The relationship of the camera sync pulses to the output data stream is determined by the camera motor characteristics. The time delay between a sync pulse and the first data bit is 40 μsec for the S/N 001 camera and 80 μsec for the S/N 002 camera.

3.2.2 Sync and Formatting

The system data format for one picture consists of 552 major frames. Each major frame corresponds to one 360° camera line scan; it consists of an upper hemisphere minor frame and a lower hemisphere minor frame. The first four major frames are for communications

TABLE II. ENCODER DESIGN REQUIREMENTS

- MECHANICAL

WEIGHT	-	2.3 POUNDS
DIMENSION	-	1.75 x 5 x 7 INCHES
RFI SHIELDED, MAGNETIC SHIELDED		

- ELECTRICAL

POWER	-	< 2.3 WATTS AVERAGE
DATA CONVERSION	-	0-4 VOLT ANALOG VIDEO INPUT 4 BIT 20 KBPS DIPHASE PCM
CLOCK STABILITY	-	0.1 PERCENT (-15° TO $+50^{\circ}$C)
SYNC CODE GENERATION	-	22 BIT LINE SYNC 9 BIT LINE IDENTIFICATION I BIT SUB-LINE I.D.

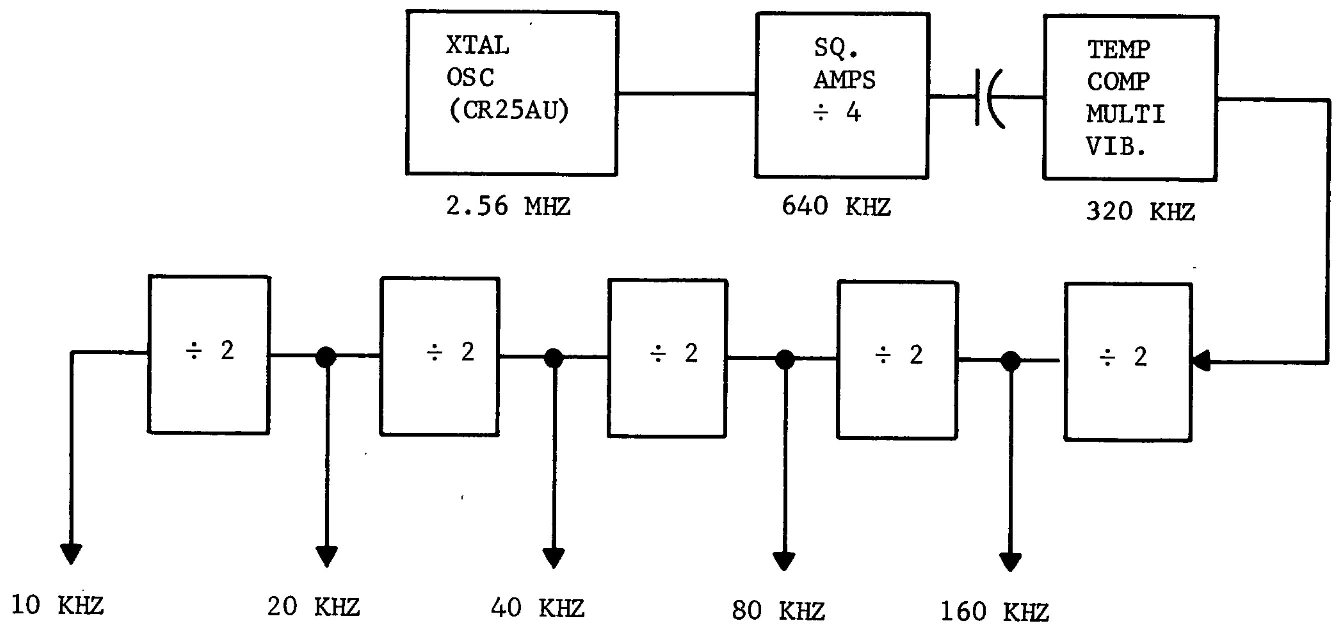


FIGURE 22. ENCODER CLOCK

acquisition; the next 512 are for active video; and the last 36 are for re-set of the scanner. Data continues to be produced in the reset interval but it is neither identified nor usable.

The output digital data format is shown in Figure 23. Each hemisphere minor line consists of 4352 20 KHz data bits. The first 22 bits constitute the sync code. The next bit is a hemisphere identification (ID) bit: a 0 for the upper hemisphere and a 1 for the lower hemisphere. The following 9 bits are the line identification bits. These identify the active 512 video lines in sequence so that the elevation of each major line can be identified in relation to the camera's field of view. The 9 line ID bits remain at 1 1 1 1 1 1 1 1 1 (Line 511) during the 34 major lines prior to the "end-of-frame" sync pulses and then move to all "0"'s for the six major lines prior to transmission of a second video picture frame. The 4320 bits following the line identification bits consist of 1080 4 bit video words except during major lines 1 through 4 where the video portion of the data is replaced by alternate "1" 's and "0"'s.

The composite data stream is buffered and delivered in both split-phase and NRZ (non-return-to-zero) form.

The output data stream for the beginning of each minor frame is shown in relation to the camera sync pulses and encoder clocks in Figure 24. Only the first video data word is shown in each case. The output signal levels are those commonly specified for standard 5 volt TTL logic circuits.

The data sequencing logic is generated by a Johnson counter. The sequence is initiated by line and sub/line sync signals generated in the

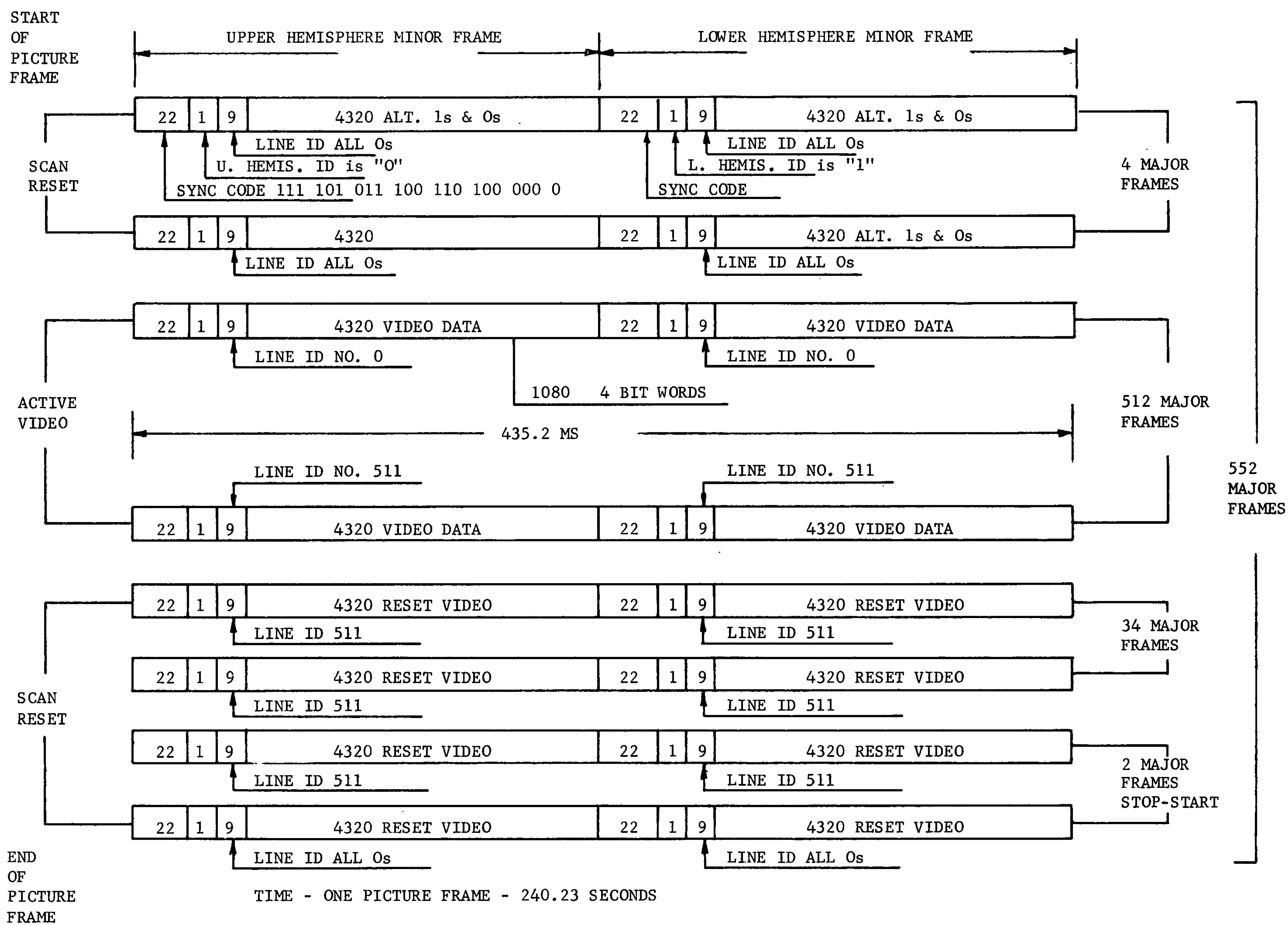


FIGURE 23. RAE-B FACSIMILE CAMERA DATA FORMAT

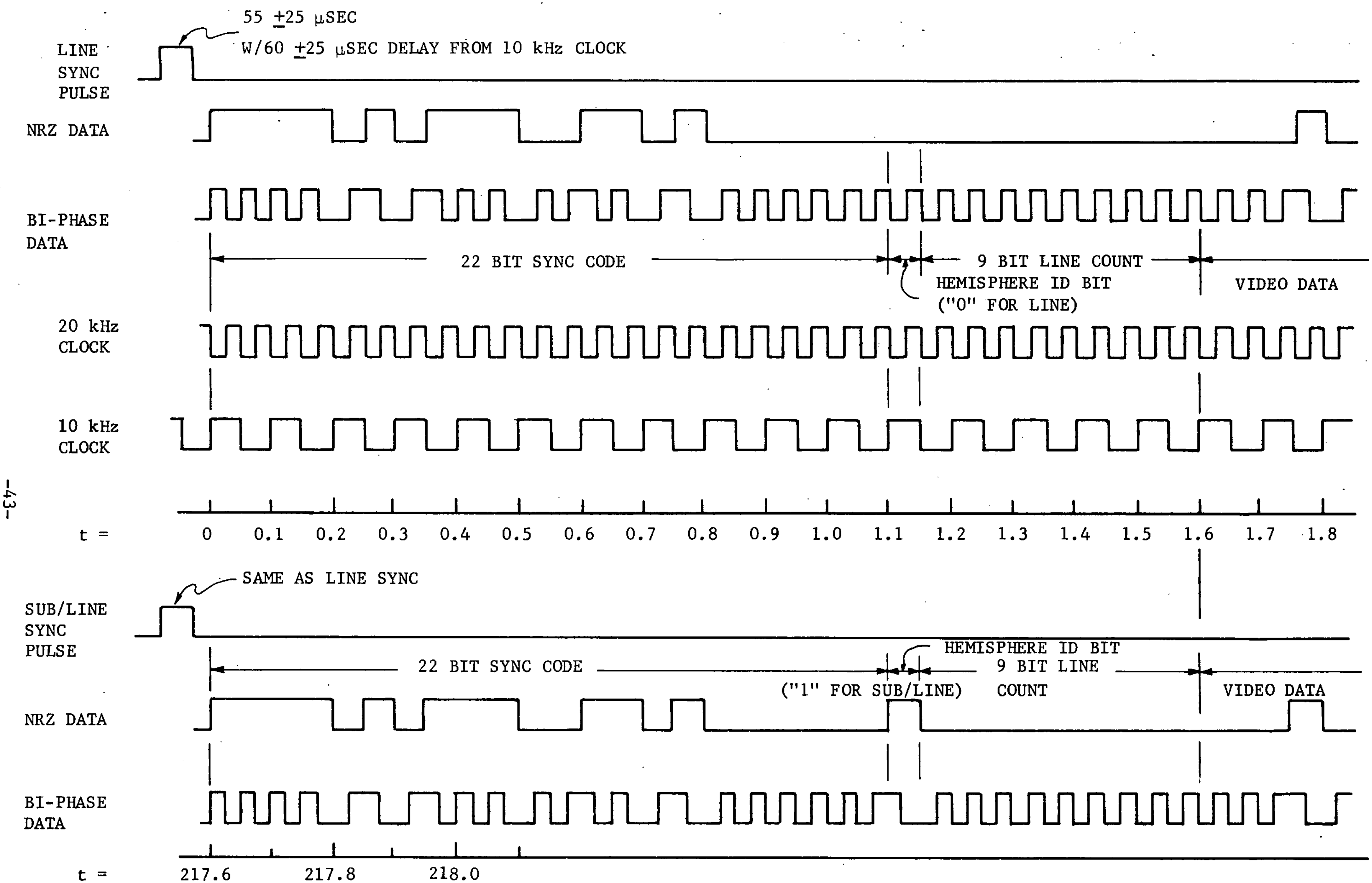


FIGURE 24. OUTPUT DATA FORMAT AND SIGNAL TIMING DIAGRAM

camera. The line identification bits are derived by a binary counter which is stepped from 0 to 511 by the camera line sync pulses.

3.2.3 Video System

The encoder video processing system is shown in Figure 25.

The signal is processed as follows: the analog video is integrated for sampling periods of 200 μsec. This 5 kHz sample rate corresponds to the camera image point scan rate. At the end of each integration period the data is fed to a sample and hold circuit, then the integrator is reset to zero, and another sampling period begins. The output of the sample and hold circuit is compared with the output of a ramp generator. The comparator output is a pulse whose time duration is proportional to video level. This pulse is used to gate 80 KHz clock pulses into a counter and this count is the encoded level which is transmitted for that particular sample period.

Noise pick up on the video leads due to their proximity to the motor drive electronics in the camera is very nearly eliminated by a 3 KHz low pass filter at the input to the encoder and by the filtering due to sample integration. Although the analog video is relatively noisy when it enters the encoder the effect is small following digital level encoding. System signal to RMS noise ratio measurements were made at both the integrator output and the sample/hold output, and this ratio exceeds 5.6 over the required temperature range at both locations.

The video encoding range and its zero level offset can be adjusted by changing gain and offset components in the encoder. Gain is set to provide the proper range of background brightness for the scene against which the boom targets will be detected. Selection of a large range of background brightness will cause the encoding steps to be excessively large. Therefore, a tradeoff must be made between the size

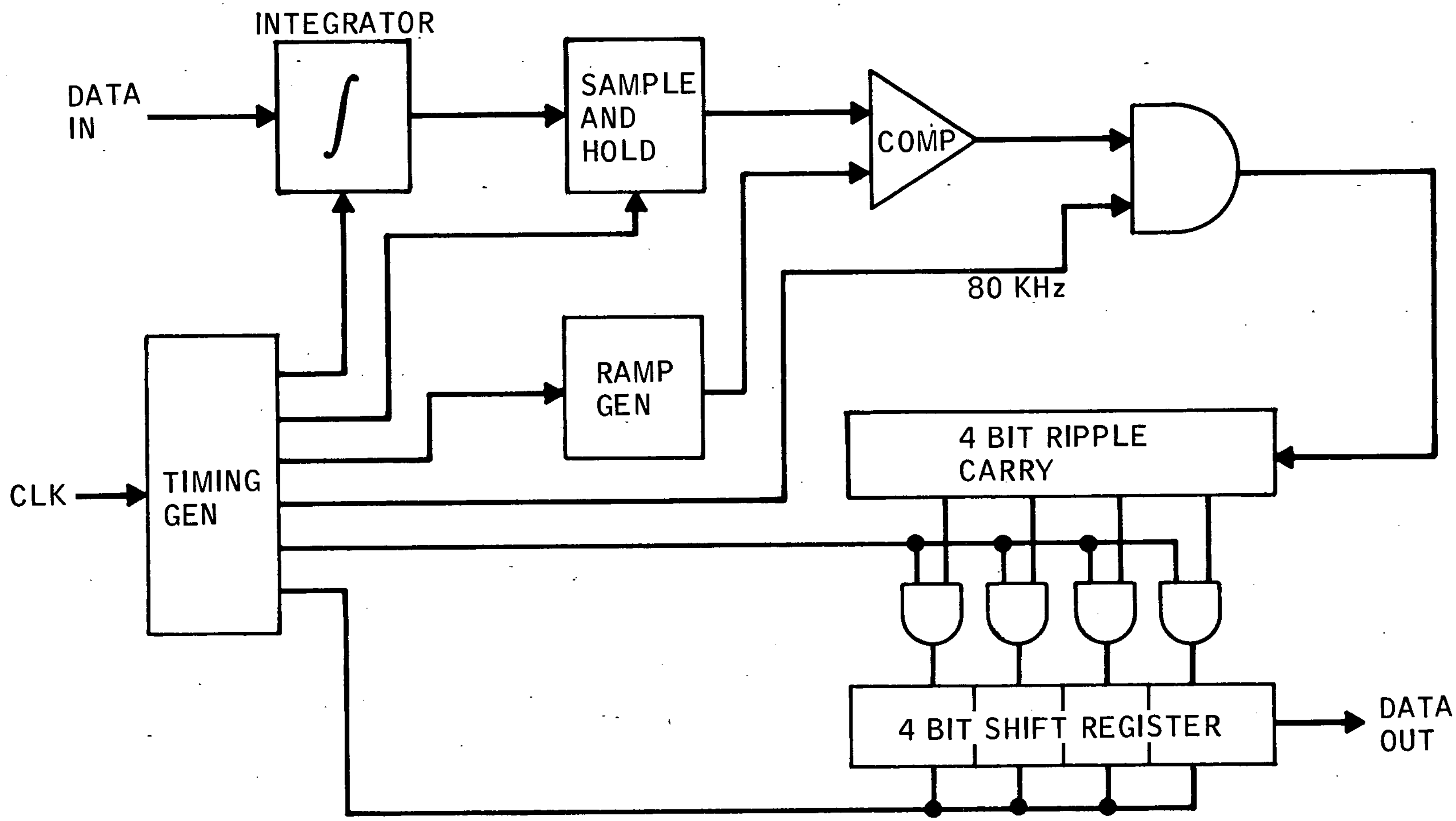


FIGURE 25. ENCODER VIDEO PROCESSING BLOCK DIAGRAM

of steps which can be triggered by a boom tip target and the range of background brightness against which it is to be detected.

In the RAE-B camera, offset is used to reduce the size of the first encoding step to increase the reliability with which a badly degraded or adversely illuminated target can be detected against a black space background. The encoding level-to-noise ratio of the system is sufficiently large to allow the first level offset to be a small fraction of the size of the other 14 levels.

The fifteen encoding levels are spaced linearly and their span can be adjusted to occur at an analog video signal level of from 1.0 to 5.0 volts. This is done by changing the reference ramp slope (by changing its timing capacitor). Three capacitor values and associated levels are shown in Figure 26. An offset adjustment is provided by trimming the reset level of the reference ramp. This is done by selecting the value of a resistor in a divider network connected at the ramp amplifier input. In this way the analog voltage corresponding to the first level may be selected.

3.2.4 Power and Control

The Camera System requires approximately 250 mA (less the heater) from a +18 $\pm$0.5 volt source (4.5 watts of power). The system power flow is shown in Figure 27. Power is routed into the Encoder for the internal DC/DC converter and for the two external cameras. The DC/DC converter generates +12V, -7V, -6V, and +5V for the Encoder and Camera circuits. The raw +18 volt supply powers the Camera motor and the light emitting diodes (LED's) in the sync and motor control circuits.

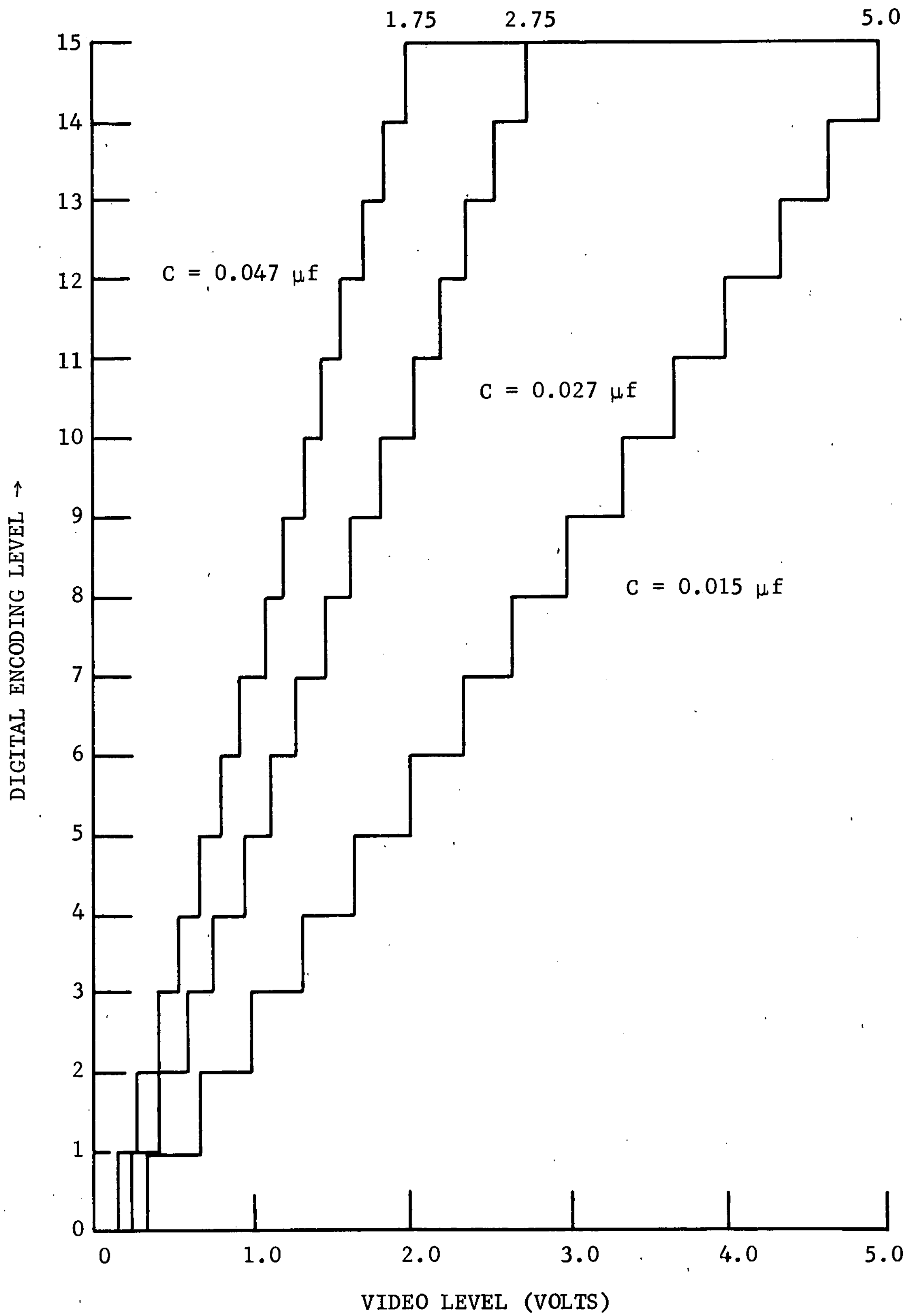


FIGURE 26. TYPICAL VIDEO ENCODING LEVELS AS A FUNCTION OF ANALOG VIDEO DATA FOR THREE VALUES OF RAMP TIMING CAPACITOR

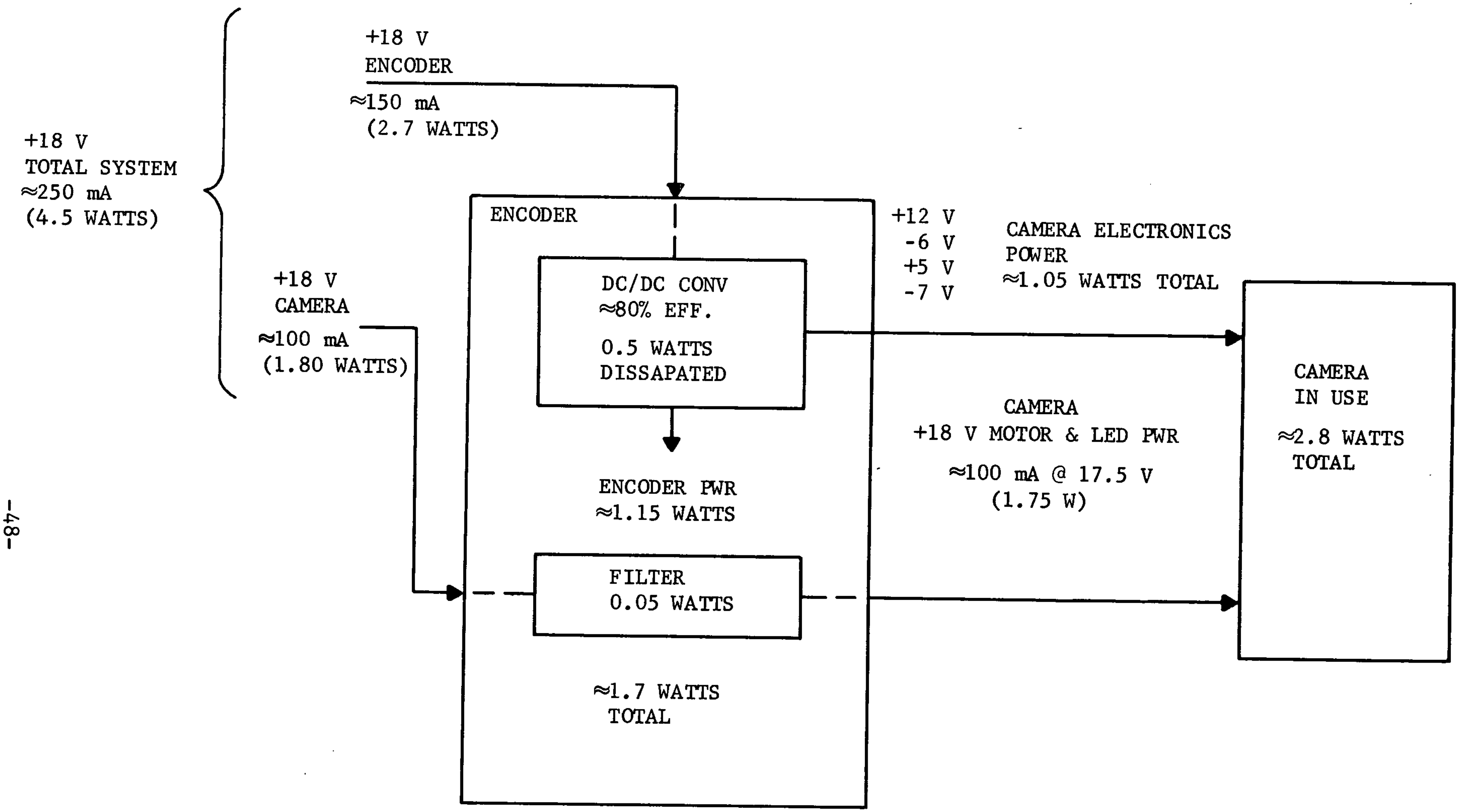


FIGURE 27. RAE-B SYSTEM POWER FLOW DIAGRAM

The system is started by applying +18 volts to the encoder power input and to the Camera No. 1 or Camera No. 2 power input as desired. The +18 volts on a camera power input switches the DC/DC converter power to the selected camera and closes FET switches which connect the necessary signal paths to the Encoder.

4.0 SYSTEM TESTING

4.1 Functional Operation

The cameras and encoders were functionally tested as a system to verify compatibility of the components. Of particular importance was the interface between the camera generated sync signals and the encoder data output stream. A timing problem was discovered in the sync logic in the encoder which resulted in a double line counter clock pulse. This was corrected by re-designing the sync pulse logic circuit in the encoder. System power requirements were measured and found to be within specification. (See Figure 27. System Thermal Test (Per SP-DB2175) was performed to determine any detrimental effects due to temperature. Three problems were uncovered. First, the camera motor control was not consistant in that start and lock was not achieved over the full temperature range. This was corrected by carefully trimming selected components in the camera to achieve acceptable operation. Second, at -15^{o}C the lower temperature extreme, or during rapid cooling of camera S/N 001 its shut-off pulse operated intermittently. The shut-off pulse would operate at the end of the next frame shutting off the camera properly. Third, at the high temperature extreme, the video signal was observed to drift positive during the initial part of a picture sequence.

Panoramic pictures were taken by each camera, out of doors, utilizing a film recorder. Three panoramic pictures are shown in Figure 28. The black target on the camera holding fixture used for dc restoration reference and badly out-of-focus foreground objects have been masked out.

4.1.1 Shut-off Pulse Failure

Camera S/N 001 shut-off pulse failed completely during testing performed at Goddard Space Flight Center (GSFC).

Engineering Model Camera

Serial Number 001 Camera

Serial Number 002 Camera

Figure 28 RAE-B Camera Pictures

This camera was returned to have the shut off pulse repaired and reduce the thermal drift of the video sensor. The camera housing was cut open and the telescope assembly and scanner assembly removed from the camera housing.

Difficulty was experienced in isolating this failure, because after opening the camera, the shut-off pulse would not fail, cold (-15^{o}C) or hot (+50^{o}C). Many thermal tests were run checking out functional operation of each component involved in generating the frame shut off pulse. The suspected component was either the video sensor or the leads from the sensor to the input of the sync amplifier. Following tests at slightly below -15^{o}C (-20^{o}C), the frame shut off pulse failed again, and diagnostic tests were run to isolate the failure.

The cause of this failure was determined to be a crack in the solder around the sensor attaching the output end of the sensor to the ceramic mounting board. This solder joint was reheated and reflowed around the sensor to eliminate the suspected intermittant open circuit.

The S/N 001 camera has completed testing during assembly and final systems thermal test (SP-DB2175) without a failure of any of the six pulses comprising the frame shut off pulse.

4.1.2 Video Thermal Drift

The details and materials used in the assembly of the video sensor and the mounting of the sensor to the ceramic circuit board were analyzed to determine the cause of the thermal drift of the video signal. The video sensor in S/N 001 camera was mounted on the ceramic board with an air gap of .030 inches between the sensor and the board. This air gap with its high thermal resistance effectively isolated the sensor from its heat sink, the ceramic circuit board. As a result the junction temperatures were running around 50°C above the prevailing ambient temperature. A thermal short was required that would displace the air gap and be an electrically insulating material.

The material selected, for its excellent thermal properties, was Stycast 2850 FT with 24 LV catalyst made by Emerson & Cummings, Inc. Prior to potting the air gap with this epoxy a thermal test of the video sensor and circuit board assembly was run to provide a base for comparison after potting the sensor. The video offset voltage versus temperature is plotted in Figure 29. Two curves are shown, the first is the initial offset voltage at video reset and the offset voltage after four minutes has elapsed. The four minute interval represents the time necessary to complete one frame cycle including 512 lines for video data, 34 lines for reset of this mirror and 6 lines of shut off pulses for a total of 552 lines. The sensor current versus temperature is shown in Figure 30 along with theoretical sensor leakage versus temperature. At 50°C ambient, the indicated temperature rise (ΔT) from the sensor leakage curve is 21°C.

These same data are shown in Figures 31 and 32 for the video electronics after potting the sensor with Stycast 2850 FT/24 LV, curing for two hours at 150°F and then vacuum baked for a minimum of two hours at 150°F with a pressure of 8×10^{-7} Torr or less.

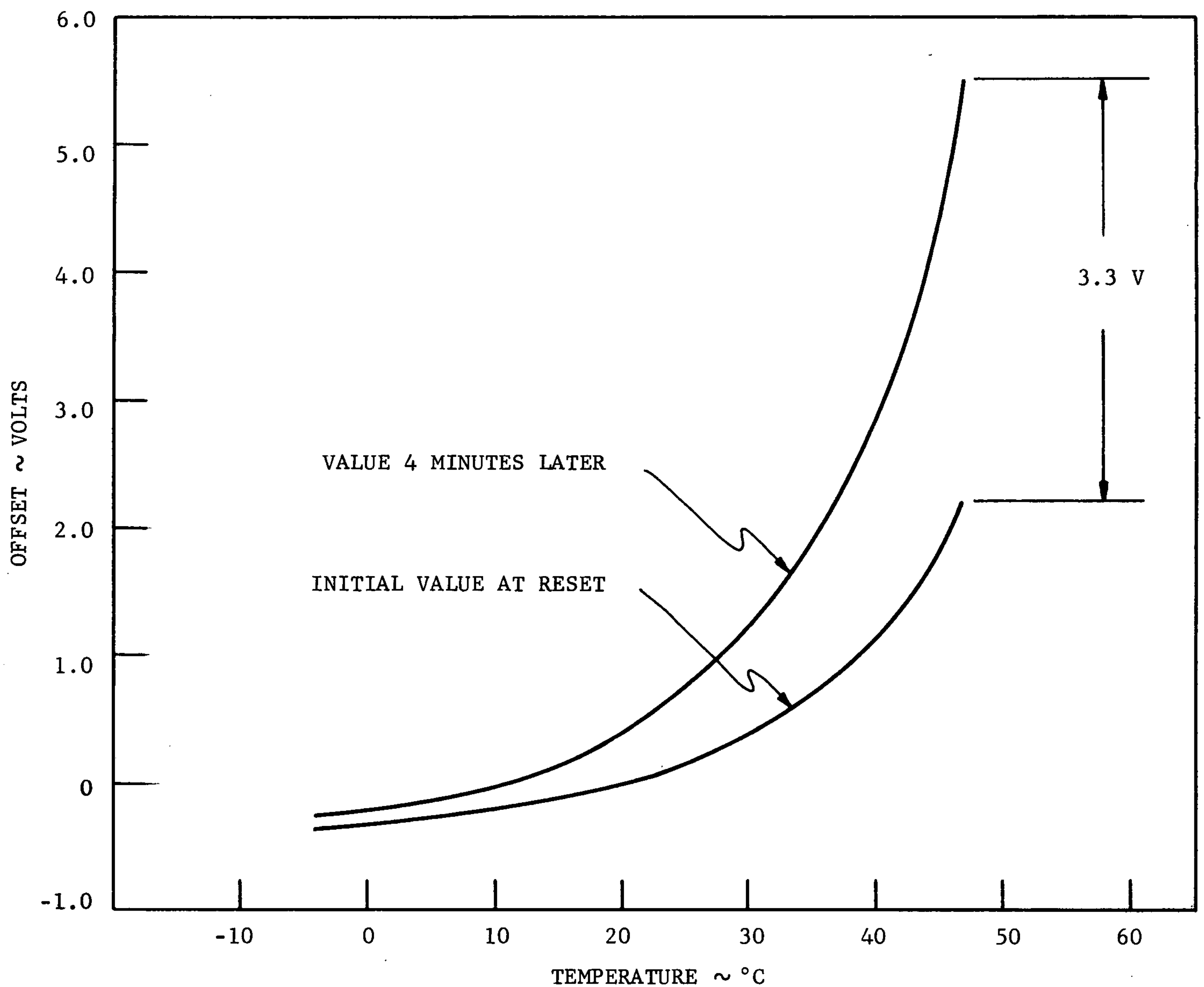


FIGURE 29. BEFORE POTTING BETWEEN SENSOR AND CIRCUIT BOARD

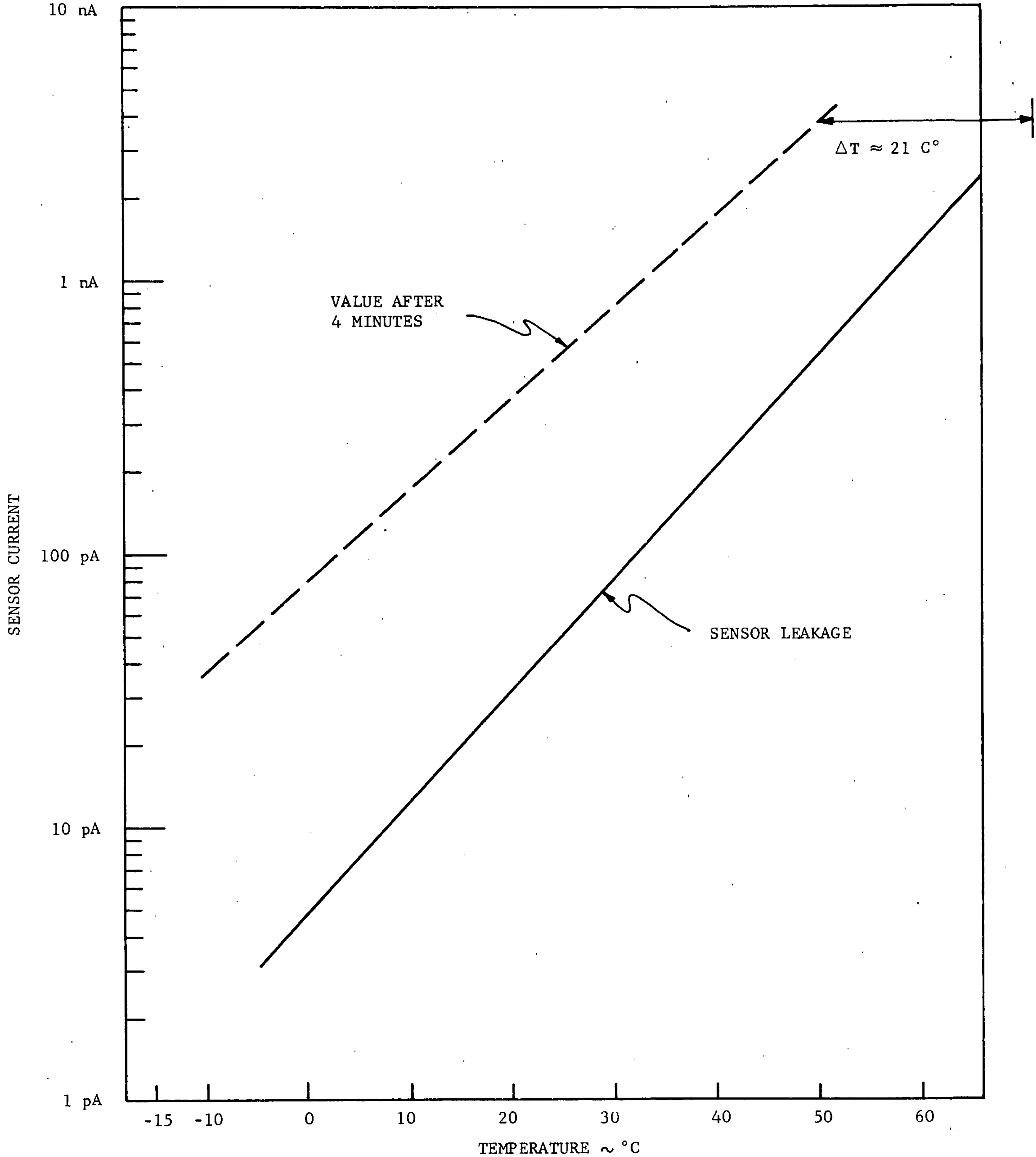


FIGURE 30. BEFORE POTTING SENSOR

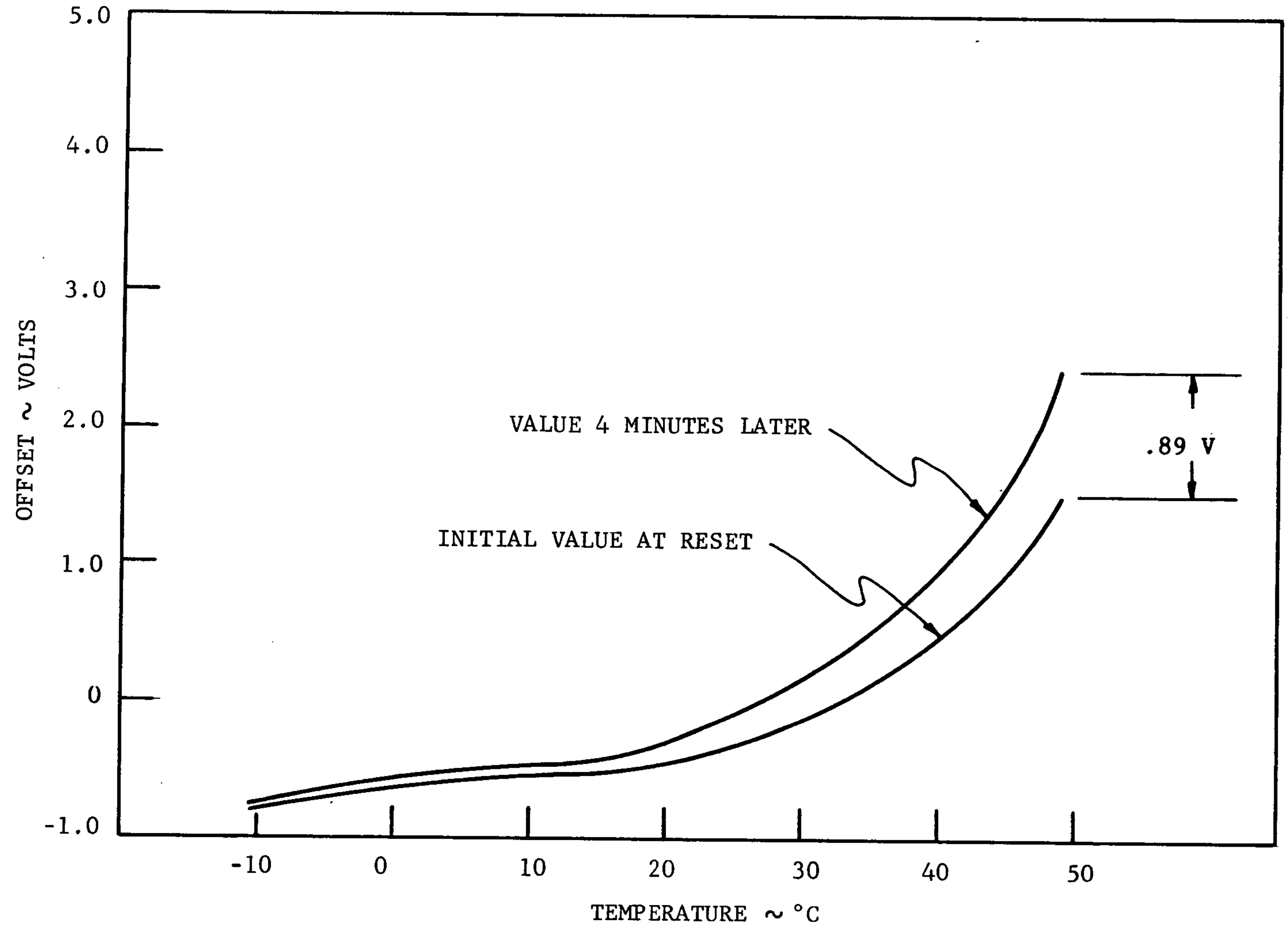


FIGURE 31. AFTER POTTING BETWEEN SENSOR AND CIRCUIT BOARD WITH STYCAST 2850 FT/24LV CURE 2 HOURS AT 150°F

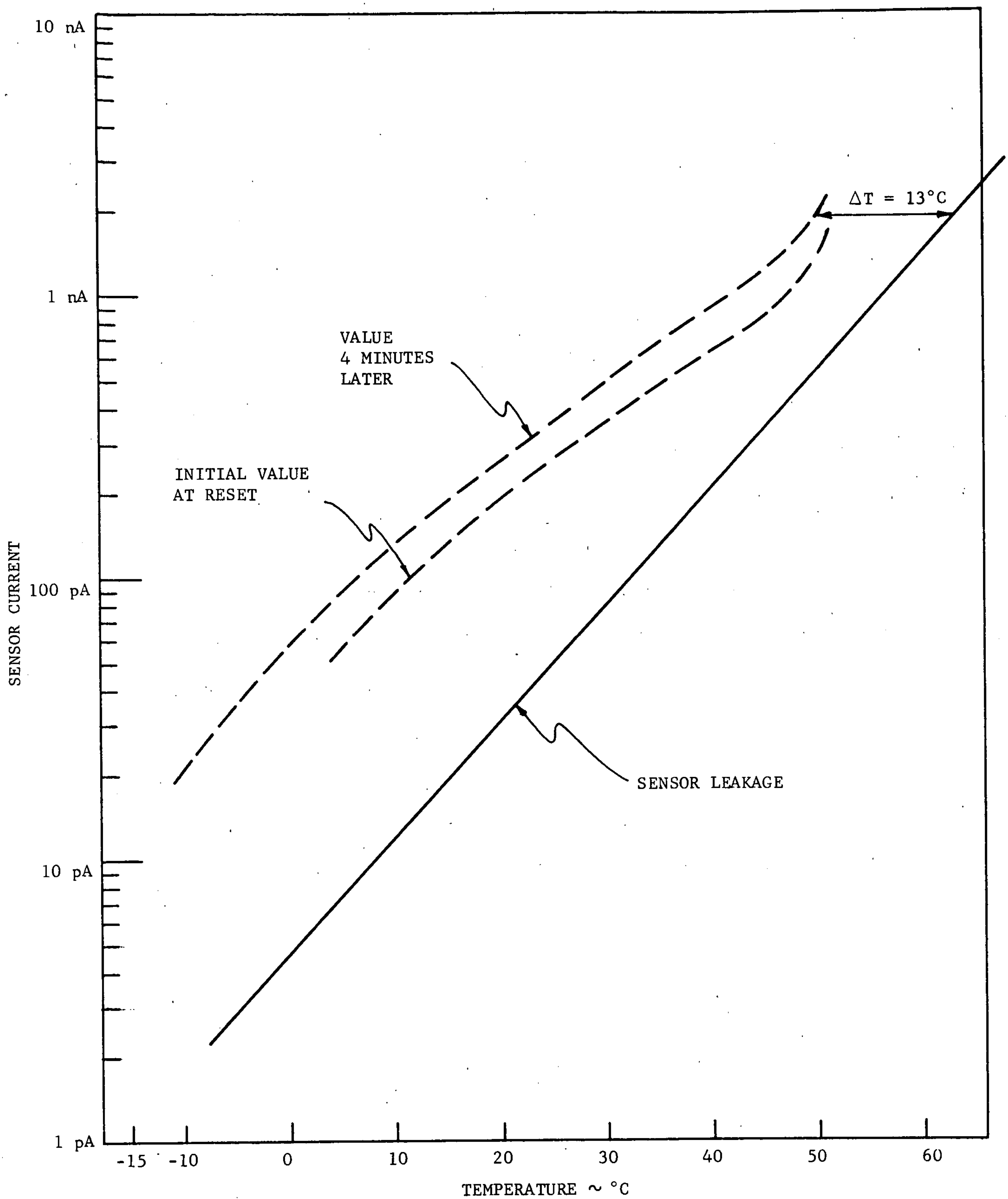


FIGURE 32. AFTER POTTING SENSOR WITH STYCAST 2850 FT/24LV

C.2

The offset voltage change, before potting, is 3.3 volts at 47°C whereas after potting this voltage change has been reduced to .89 volts at 49°C. The temperature difference from the sensor leakage curve to the curve after four minutes is a ΔT of 21°C before potting. This ΔT has been reduced to 13°C after potting, at an ambient temperature of 50°C.

4.1.3 Panoramic Pictures

After the camera assembly was welded and leak tested, panoramic pictures were taken using the film recorder. These pictures were used to insure that the field of view was scanned without overlapping lines, loss of synchronization or other mechanical anomalies. The near and far field focus of the camera was rechecked by observing the data on the negatives.

The film recorder consists of a rotating drum, with a piece of 5-inch wide RAR 2497 film mounted on it, driven in synchronization with the camera azimuth scan. A visible light emitting diode (LED) mounted on a lead screw traverses along the film drum drive in synchronization with camera mirror elevation scan. The film is exposed by this LED which is modulated by the analog camera video output signal and focussed on the film. In this manner the exposed film represents the field of view as scanned by the camera.

4.2 Signal to RMS Noise Ratio Measurements

The signal response of the cameras was measured per "RAE Antenna Aspect System Signal-to-Noise Acceptance Test Procedure AP311648" using a simulated target corresponding to the specified boom tip target. The lab setup for this test is shown in Figure 33. A uniform white background (actually a neutral density test card was used) was illuminated with GE Type DXW, IKW, 2870^{o}K lamp. An aperture geometrically equivalent to the target ball (subtending $.0286^{o}$) was placed in front of this background. The target brightness was adjusted to correspond to 10×10^{-10} Watts/cm^2 of solar irradiance at the camera. This brightness corresponds to 0.489 $\pm$ 10% foot lamberts on the Gamma scientific Model 721 linear photometer. The camera was then aimed at the aperture. A chopper was used to interrupt the target since the camera video system has no dc response, and then the peak to peak signal was measured. The signal and noise measurements were made at the integrator output and the sample and hold output in the encoder signal processing electronics just prior to analog to digital conversion. The test results indicated that the video signal corresponds approximately to calculated results, but that the noise was higher than originally expected. The noise, however, was not due to the sensor itself, but rather to motor transient signals picked up on power supply leads and then being transmitted and amplified through the video electronics. The major source of pickup was found to be the -7 volt sensor bias supply. (The signal to noise performance of the camera could be greatly improved by filtering this supply at the video sensor thereby increasing the supply noise rejection of the system.) Much of this noise is filtered out by the encoder electronics and the results of the testing demonstrated that the camera meets the required signal to noise specification. The results of the signal-to-rms-noise ratio test run 1 June 1972 on camera S/N 001 is on the data sheet in AP311648 as shown in Figure 34.

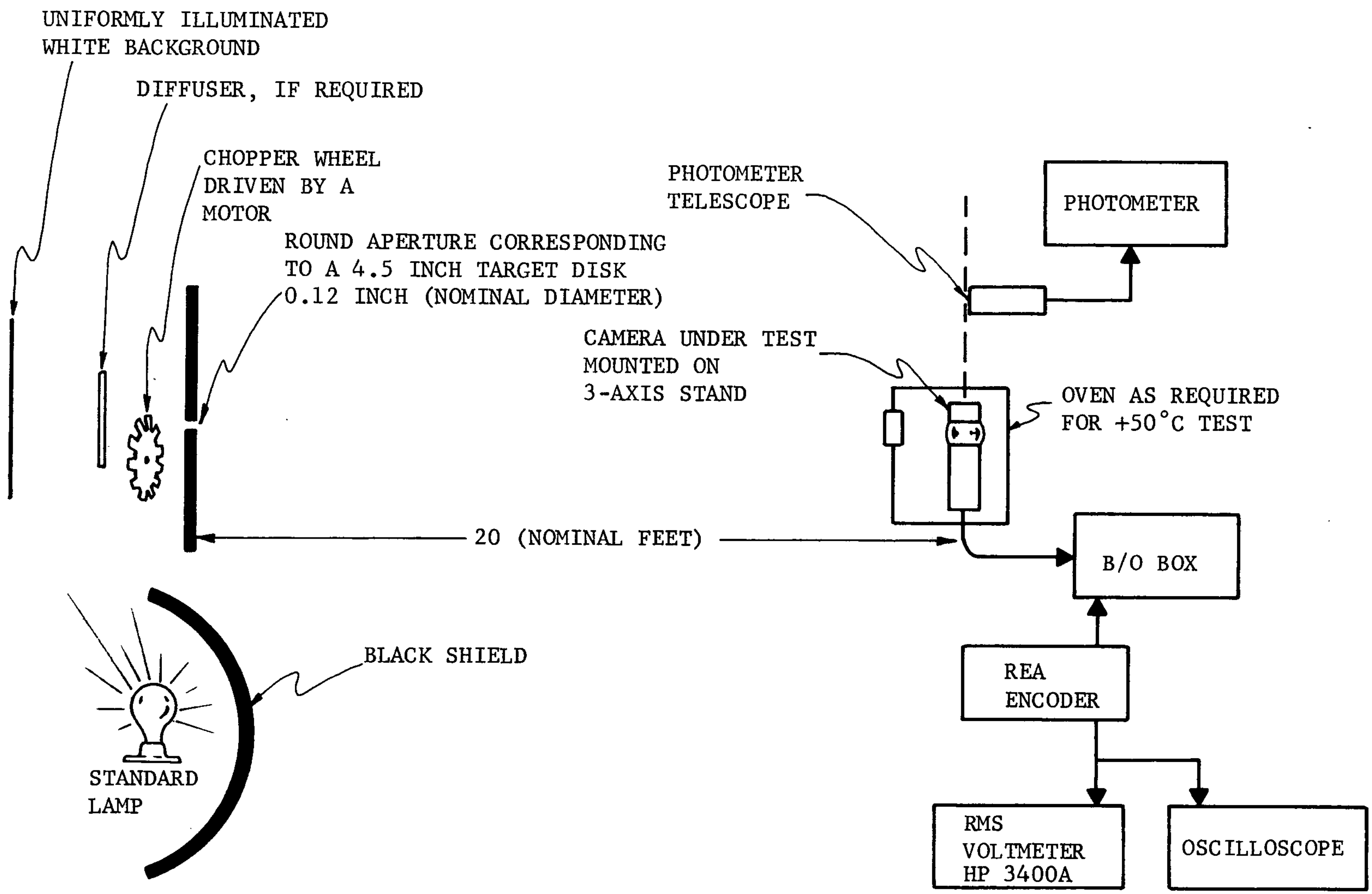


FIGURE 33. RAE-B VIDEO SIGNAL MEASUREMENT TEST SETUP

RAE-B ANTENNA ASPECT SYSTEM-SIGNAL-RMS NOISE DATA SHEET

		ACTUAL		REQUIRED
RANGE SET-UP	Aperture Size	0.12	inches	0.12
	Camera to Aperture Distance	20	feet	18' min.
	Size/Distance Ratio	.006	inches/feet	.006 ±10%
	Photometer reading	71.5	units	
	@ 0.00715 units/foot-lamberts	.511	foot-lamberts	0.489 ±10%
	Camera Temperature	21.5	°C	Room ambient
INTEGRATOR OUTPUT	Signal - Peak to peak	39	millivolts	
	Scope photo number	150-3		
	RMS Noise	6.8	millivolts	
	Scope photo number	150-1		
	Signal/RMS noise ratio	5.735		5.6 min.
SAMPLE & HOLD OUTPUT	Signal - Peak to peak	40	millivolts	
	Scope photo number	150-4		
	RMS Noise	4.0	millivolts	
	Scope photo number	150-2		
	Signal/RMS noise ratio	10.0		5.6 min.
	Camera Temperature	50	°C	50°C min.
INTEGRATOR OUTPUT	Signal - Peak to peak	39	millivolts	
	Scope photo number	150-7		
	RMS Noise	6.9	millivolts	
	Scope photo number	150-5		
	Signal/RMS Noise Ratio	5.65		5.6 min.
SAMPLE & HOLD OUTPUT	Signal - Peak to peak	38	millivolts	
	Scope photo number	150-8		
	RMS Noise	3.9	millivolts	
	Scope photo number	150-6		
	Signal/RMS Noise Ratio	9.74		5.6 min

Date of Test 6-1-72

Engineer P. Brown

Inspector [illegible]

DCAS [illegible] 6-1-72

FIGURE 34. RAE-B ANTENNA ASPECT SYSTEM-SIGNAL-RMS NOISE DATA SHEET

4.3 Calibration

Since the RAE system is required to accurately identify the location of targets in its field of view, it was necessary to calibrate each camera's field of view with reference to an alignment mirror mounted on the top of each camera. In this way, a camera can be mounted using the mirror as a reference and then the position in space of every video data point is accurately known.

A test room for calibration was set up as shown in Figure 35. Dimensions were maintained to within ± 0.04 inches and angles to within 1 arc minute.

For calibration, a camera is mounted concentric with the axis of rotation of a dividing head, whose axis is parallel to a target line on a wall. The target line extends from top to bottom of the 70-degree camera field of view and is segmented by 5 degree cross marks through the 70-degree field of view of the camera. For convenience the axis of rotation and the line were made parallel to the floor.

To take measurements the orthogonal alignment of the camera is determined from the alignment mirror and the camera is operated to scan the target line. Azimuth angle is measured with respect to line sync by starting a counter with the line sync signal and stopping it with the video signal as the scanner crosses the target. The counter counts 20 KC clock frequency cycles from line sync to target acquisition. Number of cycles counted is directly convertable to degrees of azimuth scan.

Elevation calibration is effected by counting lines to acquisition of each interrupted (short) line count, the interrupted count being caused by each of the 5-degree cross marks on the target line. The complete calibration process is described in Doc. #26899 "Calibration Procedure-RAE-B Facsimile Camera".

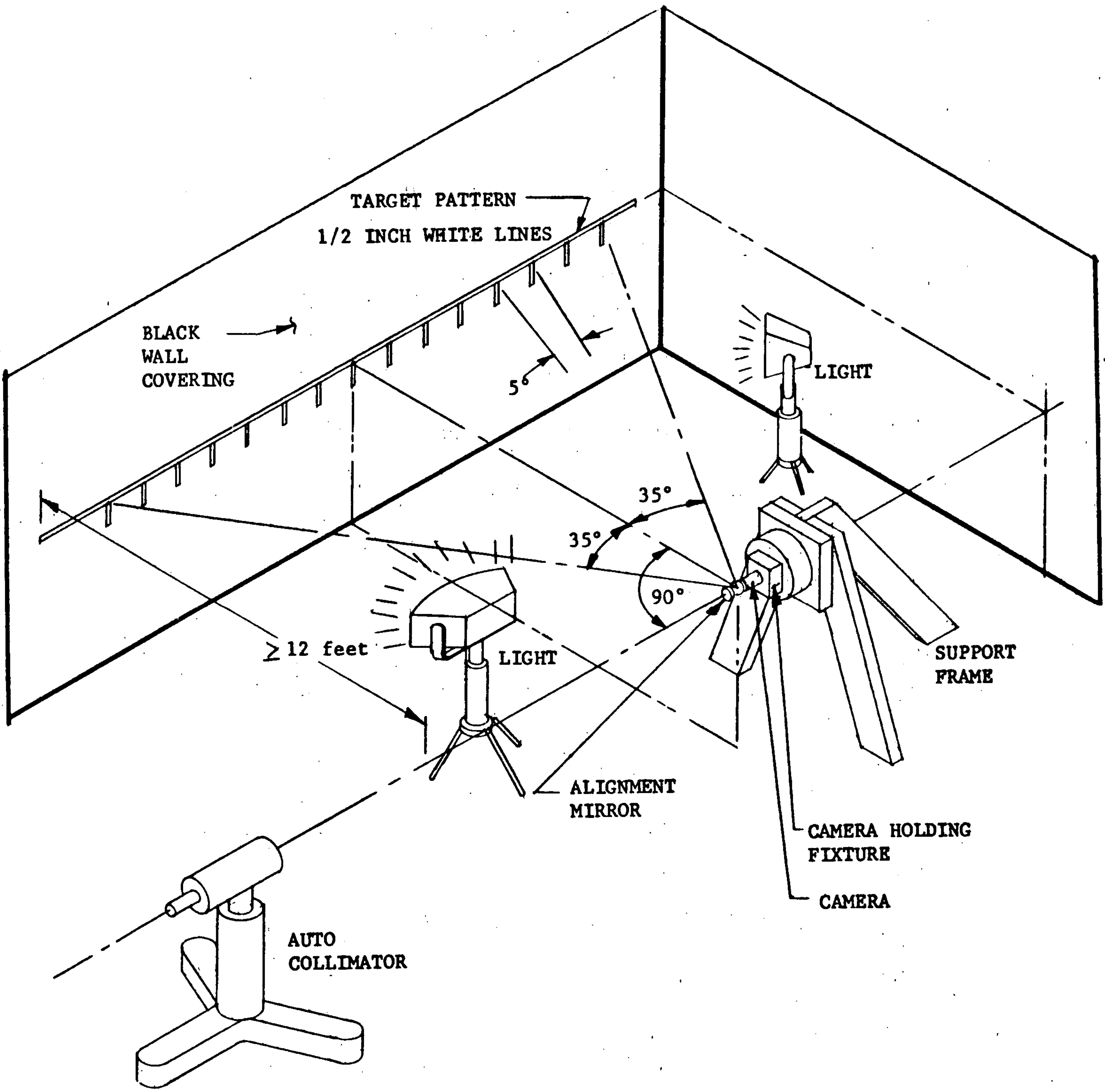


FIGURE 35. CALIBRATION TEST SET-UP

The calibration data obtained for both flight cameras indicated that the mechanical accuracy will locate targets within the required $\pm.35^{\circ}$.

SECTION 5

CONCLUSIONS

It is concluded that the RAE-B Antenna Aspect System meets all specified performance requirements.

SECTION 6

RECOMMENDATIONS

During the development, fabrication and testing phases of this program opportunities for product improvement became apparent. Normal program constraints prevented their incorporation; however the following should be considered prior to manufacturing additional RAE-B type facsimile camera systems:

a. addition of an active filter to the -7 volt power lead to prevent motor noise pickup from getting to the input lead of the video amplifier.

b. review of the motor control circuitry to modify phase error detection technique and thereby prevent the motor from locking into a lower harmonic of the synchronous speed.

c. relocation of wire runs to minimize disassembly problems.